THE STORY OF RADIO
W M Dalton
During the early years of peace after the First World War, the seepage of official information and the knowledge of wartime developments brought home by ex-service men led to an enthusiasm for radio fostered almost entirely by amateurs. They built their own transmitting stations and receivers, compelled Governments to provide public broadcasting services, and eventually astounded the world by their unaided achievements in long-distance low-power short-wave communication. This, the second volume of Mr. Dalton’s comprehensive history, pays tribute to these devoted pioneers and, in recounting the birth-pangs of the British Broadcasting Company, tells how Everyman carried on building his own receiver in a craze from which, Mr. Dalton has said, ‘a few of us never quite recovered’. 
THE STORY OF RADIO

PART 2

Everyone an Amateur

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Preface

The development of radio can be divided into a number of fairly well-defined stages. Firstly, the discovery that wireless was even possible, when scientists were constantly being surprised by facts which had been thought impossible, and when the Marconi Co., by virtue of the four-sevens patent, had almost a monopoly of transmission. This stage, described in Part I, lasted up to the outbreak of the First World War. The second stage, covered in this volume, began after the War when men trained to use wireless equipment returned to restart the amateur movement. Their activities resulted in the BBC and the amazing discovery of short wave propagation. The third stage, described in Part III, was a settling-down period when battery operated receivers, still home-made, were improved so that the family needed only simple instructions to tune-in and the quality of the sounds from the loudspeaker became appreciably better than those from the gramophone.

In a global context, the second phase 1920–1926 was still characterized by Marconi monopolies: the Fleming diode patent applied to all thermionic valves, and Franklin’s beam-aerial patent. The valve monopoly annoyed engineers most and this caused a dislike of the Marconi Co. which continued into the Second World War. A large amount of technical effort was applied to methods of circumventing these patents, but with little success. The only large evasion was by the amateurs, whom it was profitless to sue, and it became generally accepted that any amateur could use a patent,
without fee, for an experiment. Two questions arose: who was an amateur, and how long does an experiment last?

This was the heyday of the radio amateur, a survivor of the nineteenth century dilettantes, whose awe-struck family and friends were blinded with science as he described his experiments. The amateur knew all those theories which could not be proved and was dogmatic in upholding or condemning them. He knew all the words and the names, even if he was a little hazy on their meanings, and he could maintain a highbrow discussion at the local radio club without fear of betraying his ignorance of basic science.

Actually the basic science that was needed consisted of little more than the electrical theory learned in the Services and even this was subject to change as new discoveries were made. The amateur was prepared to try anything and with a large number of people experimenting, chance discoveries were bound to occur. The honour was to be first, to have a circuit or an arrangement bear your name, and in Britain the Wireless World was the recording angel.

But British amateurs laboured under severe hardships. Unlike their counterparts in the USA, they encountered continual opposition from all forms of Authority. But adversity breeds . . . , the limitations on transmitter power forced a maximum efficiency, and enforced use of the shorter wavelengths produced the jackpot. The developments over this period, mainly amateur, were so numerous that only a small portion can be recorded; I am sorry for all that I have had to omit.

It was at this time the author came into the subject with a schoolboy’s interest in the ‘wireless’. In those days you bought a ½ lb of DCC (double cotton covered) wire and 2BA nuts and bolts from the ironmongers. Where would you buy them today? This began what someone has described as fifty years of being paid for having fun. If the pay was always poor, for there were always too many other mugs with the same idea, the fun was real and few of us will ever regret the choice we made.

W. M. Dalton
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Contrary to the general belief, war does not accelerate scientific progress. In Europe, the application of the thermionic valve, which promised numerous developments in 1913, ceased when scientists were directed into war work. Governments at war require the application of known devices to military uses. These are developed and modified only if there is a military requirement, and the newest devices usually have least priority for consideration. There is little or no time available for fundamental research. When a new device is demanded by the Services, the development work is secret and withheld from the public under the Defence of the Realm Act. At the end of a war, therefore, there is always an accumulation of articles and reports waiting to be published. This gives the illusion of rapid progress but, at best, the war environment provides quick progress in a few directions at the expense of other, less military, requirements.

If a war lasts long enough, the conditions can help a young science, for men from college are drafted to the new technology, men who probably would never have thought of entering the field. Men are also taken from the older, more stable, professions to work with, and give experience to, the young enthusiasts. There is also a by-product to this, for men from different back-
grounds have to learn the subject from fundamentals, and this provides a lot of rethinking about things taken for granted. In the First World War, wireless benefited greatly from the influx of mechanical and electrical engineers, mathematicians and chemists.

**Wartime Advances**

Developments during the First World War were primarily towards improving the construction, durability, and efficiency of spark-transmitters and crystal receivers so that they would withstand handling by unsympathetic Service personnel. The onset of trench warfare caused a demand for portable wireless apparatus for the advanced units. Wireless had the disadvantage that it radiated in all directions and required a high degree of coding for secrecy, but it did give reliable communications, while those by telegraph or telephone were prone to constant failure due to shell fire; necessary repairs to cables could only be made at great personal risk. Nevertheless, the equipment had to be light enough to be carried by not more than two men, and had to withstand being dropped, kicked, stood upon, or bounced by the effects of explosions.

Initially, a crystal receiver was used, but signals were not always available to enable a sensitive spot to be found on the crystal, and a tuning buzzer gave sufficient radiation for the enemy to locate the receiver; thus valve receivers were soon demanded. These needed high selectivity if the operator was to tune out interference from other stations or deliberate jamming by the enemy.

Valve transmitters were also demanded. Little power was required to send over short distances, and the size and weight of the valve set was shown to be less than a spark set, while the cost was about the same. The valve transmitter also had one big advantage—its silence—for the crackling of the spark could be heard a long way on a quiet night. Another advantage of the valve set was
the ease with which its wavelength could be changed to dodge enemy listening posts. Later, much shorter wavelengths were used to avoid enemy reception.

But even the best equipment would have been useless without a large number of efficient operators. Many of these were recruited from the ranks of the amateurs who had made wireless-telegraphy their hobby before the war. These men set, and maintained, a standard of operation which was often higher than that of professionals. They also suggested many improvements and, after the war, it was they, individually and through their clubs, who provided the information about wartime advances. It was their lectures, rather than the official reports, that made known these developments.

Valves and Circuits

The provision of valve equipment necessitated the production of quantities of valves, where previously they had been made singly or only a few at a time. This required much development work. Not only were machines required to provide the component parts, but replacement materials were often necessary for metals which became scarce as the war progressed. The allies centralized much of this work at the Etablissement Centrale de Telegraphie, under General Ferrie, and the “French valve” became the standard for all receivers.

The construction of this valve (styled “R”, for receiving) was similar to the Round valve (see Part I, Chapter 4), with a straight filament consuming 0.52 A at 3.75 V, which was surrounded by a spiral grid and a cylindrical anode (see Fig. 1.1). The vacuum was high enough to allow 75 V at the anode without a blue glow, and the life of the valve was about 5000 hours. The valve was set into a small metal cup which carried four pins, two for the filament and one each for the grid and anode.

In 1916 Sody improved the vacuum of the valve by means of a
"getter", a small piece of magnesium inserted inside the tube. After running on the pumps to get the best possible vacuum, the tube was sealed and the magnesium fired, its action being to collect any traces of gas which remained in the tube and to seal these onto the inner surface of the glass where they formed a black film. Getters of this type were enormously improved at a later date by the Kennet Co. in the USA.

Larger valves which would handle more power were also required for transmitters, and scaled-up versions of the receiving valve were made to provide larger anode currents. Typical valves operated with anode currents of 25 mA at 500 V h.t. and 50 mA at 750 V. Greater spacing was required between the electrodes to prevent flash-over with these higher voltages. The larger emissions necessitated larger filaments and this required more heating power. This heat had to be radiated and so the glass bulb also had to be
larger. The design of such valves entailed investigations into the
theory of valve emission and into the circuits in which the valves
were used. Many British lamp manufacturers were encouraged to
make these valves during 1916 and 1917.

The workers under General Ferrie investigated all the known
valve circuits. Van de Bijl studied detector circuits using both diodes
and triodes at audio frequencies. He compared the input signal
strength with the detected output. Leibowitz and Bethenod gave a
comprehensive analysis of detectors using both linear and curved
characteristics, and others examined detectors in heterodyne
reception. In the USA, Armstrong in 1917 described experiments
with crystal and valve detectors using separate and self-heterodyne
methods. By varying the strength of the heterodyne oscillator he
showed there was an optimum value for the oscillations which
depended on the strength of the incoming signals.

Attempts to analyse the audio-frequency amplifier were not very
successful. The transformer caused the amplification to change
both with the amplitude and the frequency of the signal. Neverthe-
less, a generalized theory of the operation was produced, with
curves showing the change of anode current for various grid
voltages. The amplification of the valve was shown to equal the
ratio of the changes of anode and grid voltages which gave the
same change of anode current, i.e. amplification \( \mu = \frac{dV_a}{dV_g} \).

In 1916 Brillouin and Beauvais patented the resistance/capacity-
coupled amplifier (see Fig. 1.2). The amplification from this
circuit compared unfavourably with transformer coupling, for the
step-up ratio of the transformer was equal to that of the valve,
but a six-valve RCC amplifier was remarkably stable while a
three-valve transformer-coupled amplifier of the same overall
amplification was prone to stop operating for no apparent reason.
It could also break into a prolonged howl which could only be
stopped by switching off the h.t. supply. This RCC amplifier was
analysed and a simple theory of its operation, given by Latour,
enabled the amplification of a complete stage to be accurately
predicted. This was followed in 1917 by Valauri’s analysis of a valve when acting as an oscillator, rectifier or amplifier. Valauri ignored the steady anode current and regarded the valve as an alternator having an internal resistance \( r_a \) and an emf equal to the input signal \( E_g \) multiplied by the amplification factor \( \mu \) of the valve. This generator operated into an anode resistance which formed the load \( R \) to give an output \( M \) given by:

\[
M = \frac{\mu E_g R}{R + r_a}
\]

The theory of the valve transmitter was also examined, for the difficulty of providing h.t. power made it essential to have the highest efficiency. In practice, a man could provide about 40 W of power by rotating the handle of a generator, or 200 W when pedalling a dynamo mounted on a bicycle frame. A picture of a German unit in East Africa showed a tandem bicycle to provide 500 W (four-foot power).

Electrical engineers who had been drafted to work on radio transmitters tried to measure the efficiency and used this to find the sources of waste power. Measurement of the input d.c. supply was easy, but the output radio-frequency current was more
difficult. Hot-wire meters, the only ones suitable for such high frequencies, were of little use, for the current was usually less than 1 A, and could only be related to power if the resistance of the circuit was known.

An aerial was known to act mainly as a capacity and only the resistance of the tuning coil, the aerial wire and the lead-in could be measured. But these engineers worked on the assumption that the generated power was expended usefully as radiation and wastefully in the resistance of the circuit and the valve. A method of assessing the radiation resistance was found by the use of an artificial aerial which consisted of a calibrated variable condenser in series with a non-inductive resistance, wound in a manner suggested by Ayrton and Perry with two wires in opposite directions; these wires shared the current and created two opposing magnetic fields. After the transmitter had been tuned to give a maximum current using the normal aerial and earth, the wires were disconnected and the artificial aerial connected. The capacity was adjusted to give the same wavelength and the resistance was adjusted for the same aerial current. Then, after subtracting the resistance of the aerial and earth leads, the resistance remaining was equivalent to that of the radiation.

Experiments showed that small oscillators fitted with a grid condenser and leak used less anode current for the same output power. The oscillations at the grid were shown to produce a negative charge, as with the cumulative-grid detector, and although this charge was continuously leaked away, the grid remained negative to reduce the anode current without reducing the power output. It was found that too high a grid resistance caused the output power to fall, or there was an optimum value for maximum efficiency. Grid leaks were quickly introduced into all transmitters. The reduction of anode current permitted higher anode voltages to be used without the anode melting; the anode was always run red-hot when the key was pressed, but it usually had time to cool again when the key was raised.
Direction-Finding

Directional transmission had been tried for avoiding reception by an enemy, but it was not very successful. Directional reception, however, did help to remove jamming. The idea of concentrating the energy into one direction had been suggested from the early days. Both Hertz and Marconi had used reflectors in their experiments, but ships' communications required all-round working and the trend to long wavelengths had made reflectors impractical.

In 1902 Stone patented a method of directional transmission and reception using aerials spaced half-a-wavelength apart, but this was not practical with long-waves. In 1899 Braun had used a loop aerial for transmission and reception. De Forrest in 1904 had also used a loop aerial based on the Hertz resonator, but to receive adequate signals the loop had to be large and have a number of turns; stronger signals could always be obtained with the open aerial.

A use for directional reception, which had been developed quite early, was to find the direction of a transmitter, and consequently the position of a ship at sea. If a ship which had lost its bearings in the English Channel could find the directions of the transmitters at Clifden and the Eiffel Tower, two lines would be drawn on a map for these directions, and where the lines intersected was the position of the ship.

Use was made of an L aerial which gave a larger signal, sending or receiving, when pointing away from the desired station. In one station, thirty-six aerials were erected, spaced around a circle, with a switch to select the one giving the loudest signals. The difference in signal strength was small, however, and it was almost impossible to choose which aerial was the best.

An ingenious solution to this problem was described by Bellini and Tosi in 1907. They used four aerials sloping from a central aerial mast at right-angles to each other. (Fig. 1.3) The four lead-in wires were returned to the base of the mast where they were con-
connected to four coupling coils mounted one on each side of a radiogoniometer (Fig. 1.4). There was a fifth coil rotating within the other four to transfer the signals to the receiver. This aerial was modified in 1912 by Prince, who used two large triangles of wire facing north-south and east-west. In this aerial a signal arriving from due north gave different currents in the north and south aerial wires, while the currents in the east and west wires were equal. The coils in the radiogoniometer were arranged so that current in opposite aerials opposed each other. When the rotor was facing the north or south coil a signal was heard, whose strength depended on the difference of the two currents. In the same way a signal
from east or west gave nothing when the search coil faced north or south, and loudest signals when it faced east or west. When a signal arrived from the north-east there was a difference signal in both pairs of wires and coils, but these were additive. No signals were received when the search coil faced north-west or south-east and the signals were maximum when the rotor faced south-west or north east.

In practice, it was difficult to find the position of loudest signals, but the positions of the minimum signals could be located within a few degrees. After having found the minimum position, 90° could be added or subtracted to this bearing to give the true position of the signals. The position of a ship was usually known sufficiently well for the ambiguity to give little trouble, but even this chance was removed by Pickard, who in 1907 patented a combination of the normal aerial and a loop to provide “sensing”. The normal aerial was connected to the receiver to tune-in the signal and the receiver was switched to the loop, which was rotated for minimum signals. Then both aerials were connected and the loop was turned through 90° again for a minimum signal, which was in the opposite direction to that of the signals. In a paper to the IRE, Pickard gave
Fig. 1.5 (Top) Heart shaped aerial; (left) Loop aerial; (right) Box aerial
several combinations of aerial and sizes of loop. The Marconi Wireless Telegraph Co. used the normal ship's aerial and a Bellini–Tosi aerial to provide direction-finding at sea. All this, it must be remembered, was before the advent of valve amplifiers and when signals were too small to give accurate directions. During the war a number of valve stages were added, and with a 30 ft. high Bellini–Tosi aerial the system became very useful. It was one of the key weapons of the First World War.

A number of D/F stations were erected around the coast of Britain and these constantly checked the positions of enemy transmitters. Two or three stations were used in combination to plot the directions of such transmitters and their positions were found with great accuracy. By this means the flight of a Zeppelin airship was watched from its hangar to the English coast and a position to intercept it was predicted. Similarly, the positions of submarines were plotted when they surfaced to transmit messages. It was by plotting the movement of the German Grand Fleet down the Kiel Canal that the Royal Navy was able to engage in the Battle of Jutland.

Apart from the Bellini–Tosi aerial, two types of loop aerial were used during the First World War. One was a wooden cross with wires held in slots to make a flat spiral, and the other a wooden box with the wires wound around the sides to make a short helix (see Figs. 1.5b and c). Blatterman showed that this type of aerial operated from the magnetic component of the radiation field, which was at right-angles to the vertical electrical component used by the open aerial. The signal picked up depended on the area of the loop, the number of turns and the transmission wavelength. He drew curves which showed the optimum area, number of turns, gauge of wire, and spacing between the turns for any given wavelength.

On the long waves a smaller loop with more turns was needed, but this could produce a directional error. There was a difference signal between the first and last turn of the loop even when it was set at right-angles to the station, meaning that there was no zero
signal. An error could also be obtained because the loop acted as a normal elevated wire and picked up signals from the electrical component of the field. Both these effects gave false zeros. The wires from the loop to the receiver, and the receiver coils themselves, could also pick up the vertical signal, so lead-covered wires were used between the loop and the receiver, and the receiver and its batteries were enclosed in a metal box, to prevent these errors.

**Wireless-Telephony**

The demand for wireless-telephony came from the RAF, where the use of wireless in aircraft was cursed more often than it was praised. Its usefulness for reporting the movements of enemy troops or the effects of gunfire on a target was apparent, for even if the aircraft was shot down the information had been passed to base or the gun battery.

The objections of pilots were understandable, for not only did the wireless receiver connect them to orders from the ground when they wanted to be as free as birds, but the wireless equipment made

*Fig. 1.6 Early Marconi radiotelephony set*
the aircraft more vulnerable to enemy fighters. No pilot could send and receive morse at more than five words per minute, so an operator was required, making a two-seater aircraft essential for observation. Such machines were slower and less manoeuvrable than a single-seater aircraft. Wireless-telephony would allow a single-seater aircraft to be used and the pilot could report directly.

Another complaint was that interference picked up from the engine was reduced by metal screens around the ignition cables and these reduced the spark at the plugs, which could cause the engine to fail—an important consideration when aircraft had only one engine. Then there was the aerial wire which hung below the aircraft; all the metal parts of the aircraft were wired together to form the other plate of the radiator. Before transmission or reception could

Fig. 1.7 Aircraft transmitter and accessories: A, aerial reel; C, control unit; G, wind-driven generator; H, headphones; M, microphone; T, transmitter.
take place, some 200 ft of wire was reeled out from the observer's
cockpit. If evasive action was necessary, the time taken to reel in
this wire was far too long. Also the wire was held down by a
weight, which was prone to twist itself off. Then the wire coiled
itself around the rudder or ailerons with speedy disaster. Of
course, the quick use of a pair of wire-cutters did overcome the
first objection, but the second trouble remained even into the
Second World War, and as late as that, the pilot was only too
happy if the radio was unserviceable.

The introduction of telephony was delayed for a long time
because some early experimental transmissions were heard in
France, but towards the end of the First World War small radiotelephony sets were installed in single-seater aircraft. The sets had a
range of about 30 miles between air and ground and about 5 miles
between aircraft. Valve transmitters were used, and half the full
power was radiated when the pilot was silent. Speech caused the
output power to vary at the frequency of the sounds; at the re-
ceiver this gave a varying pull on the earpiece diaphragm to
reproduce the speech.

The microphone was tried in every position in which the transmit-
ting key was used. When it was put in the aerial circuit its
resistance varied the r.f. current, but much of this current was
bypassed through the capacity of the connection leads instead of
going through the resistance of the microphone, so that even shout-
ing gave little change of aerial current. An improvement was
obtained by using an additional valve, connected across the tuning
coil to absorb half the power. The microphone was connected
between the grid and filament of this valve to vary the current absorbed.

The microphone transformer was also connected in the anode
circuit of the oscillator valve to vary the voltage of the h.t. supply,
but the changes were not sufficient and it was necessary to amplify
the microphone voltages. In this anode modulation system, which
was favoured by the RAF, the output transformer of the amplifier
was connected in series with the h.t. lead, and for full modulation
the amplifier provided the same voltage as the supply to vary the
oscillator voltage from zero to twice the h.t. voltage.

Heissing connected the modulation valve in parallel with the
oscillator. Two similar valves were used and with no current the
two valves took equal currents from the supply. An iron-cored
coil connected in the supply lead prevented changes of current from
the supply, so that an increase of current in the modulator valve
could only be had at the expense of the current in the oscillator
valve. When the current decreased in the modulator valve the
oscillator current increased.

The microphone transformer could also be connected to the grid
of the oscillator valve so that the valve amplified both the r.f. and
a.f. currents and mixed them together. This circuit worked well
and saved the extra valve. It was greatly favoured by the American
forces, but the effects of grid current made its action quite compli-
cated.

High-power Valves

The success of the small, mobile, valve transmitter caused
demands for higher power both for the Army base units and for
RAF ground stations. Valve transmitters, even with powers of
100 W and over, were of little use to the Royal Navy, for all the
large ships had arc transmitters and even the small ships had a $1\frac{1}{2}$ kW
spark set.

At first, increased power was obtained by operating valves
in parallel, as suggested by Round in 1914, but later special valves
with anode ratings of 200 W and 300 W were produced. A
typical valve, the 7RR3, was modified to the Marconi MT2, a
300 W valve with a glass envelope of 7 in diameter and 17 in long.
The bulb was re-entrant at both ends in order to hold two metal
bands supporting the electrodes. The filament was made as a
U with a spring at its centre to keep it taut when hot, and the grid and anode surrounded this as with the normal valve (Fig. 1.9).

The filament was thicker than Richardson’s formula required and although this needed more heating power, the waste was balanced by a longer life. To prevent overheating, the filament voltage which gave 90 per cent of the full emission was marked on the glass. Running below this marked voltage gave a longer life to the valve. No base was provided, the valve being seated in a wooden support with a large hole. The leads which passed through
the glass were taken directly to the other component by flexible wires strung with ceramic beads.

The circuits used with these valves were very similar to those for small powers, and the components were made larger to withstand the higher voltages and currents. The h.t. supply, usually about 10 kV, was obtained from a number of d.c. machines in series.
Each generator had to be insulated from the others and from earth and the maintenance of such machines, even cleaning the commutators, was dangerous.

The improved efficiency obtained by using a grid leak permitted the h.t. voltage to be raised while still keeping the watts within the rated dissipation of the valve. This, however, raised a problem when tuning. If the valve stopped oscillating the anode current increased due to the lack of bias, and the dissipation of the valve was exceeded, causing the anode to melt. This condition was easily obtained when adjusting the aerial coupling, for when this was too tight the resistance loading could stop the circuit oscillating.

**Ships' Installations**

The apparatus in liners and other commercial shipping changed very little during the First World War. The pre-war transmitters were still in use, usually fixed or rotary spark types having a power of between 0.5 kW and 1.5 kW. The receivers were either crystal or magnetic detectors. An emergency transmitter was often fitted, consisting of an induction coil operated from accumulators which were charged from the ship's mains. Valves were seen only in the largest ships, which sometimes had valve receivers consisting of a multiple-tuner, a detector and a note-magnifier. This was regarded as a nuisance, for any trouble with the spark transmitter or the crystal receiver usually resolved itself into a mechanical problem which was within the capabilities of the engine room staff. Valves were beyond the technical knowledge of even the chief operator, making it unlikely that they could be repaired. All communications were with spark or interrupted-arc transmitters which sent out wavetrains. The operator selected one transmitter from another by its note and the style of the keying. Many operators could even tell which one of the station staff was at the key by his method of sending. A ticker could be used for listening to c.w. shore stations, but this was not usually necessary, for these stations.
seldom communicated with ships, and even valve receivers had no reaction.

After the First World War the regulations governing the installations in seagoing ships were changed and wireless apparatus and qualified operators became essential in all ships entering British ports (an exception was made of the ships engaged in the coasting trade). The number of operators required depended on the class of ship and the duration of its voyages. A liner was required to have three operators, one of whom had to have a first-class certificate. A ship with less than fifty passengers and crew needed only one second-class operator.

These regulations should have provided a large number of jobs for ex-servicemen, but few of the wartime operators were attracted to the sea and there was a shortage of qualified men. To overcome this, certain ships were allowed to use a “watcher”. He was normally a member of the crew who had shown that he could pick the distress and the emergency signals from any collection of morse signals. If he heard either of these signals he was supposed to call the operator back on duty. Watchers were usually described as hibernating animals for, fortunately, such signals were seldom heard.

Very few ships were fitted with D/F apparatus. Indeed, even in ships which were so fitted, it took a long time for the equipment to

Fig. 1.10 Marconi direction finding receiver (1923)
be regarded as anything other than useless. Masters would not accept a wireless fix which differed from their dead-reckoning and, even after the war, many captains found it difficult to realize that wireless signals could be received through a fog, let alone provide bearings. Some of the blame must, of course, be borne by the operators, who, knowing little about navigation, sometimes gave impossible bearings from the apparatus.

After the war a number of the D/F stations around Britain were retained to assist shipping and bearings were given at a cost of 5s each. The ship transmitted its call-sign while one or two of these stations took bearings which were then transmitted to the ship. Even those stations which had been specially designed for direction-finding could give wrong bearings, though these were seldom more than 2° in error for distances of up to about 75 miles. There were some errors inherent in the mechanical construction of the scales, the layout of the apparatus, poor adjustment, unstable r.f. amplifiers, and various forms of feedback into the aerial system. Even the c.w. heterodyne oscillator was sometimes picked up by the loop to distort the bearing. But most of these were known and could be allowed for when giving a bearing.

Some troublesome errors were caused by the site on which the station was established, for conductors such as barbed-wire fences, telephone wires, and even metal ores in the ground distorted the direction of the signals; but usually these errors were less than 5° if the site had been carefully chosen, and a curve of quadratical error similar to that used for ships’ compasses corrected these errors.

Ship-to-shore bearings were also found to have an error similar to the refraction of light when passing from one medium to another. This coastal refraction was ascribed to the different conductivities of land and water. It was usually a constant amount, depending on the angle of the incoming signals, but it varied with the state of the tide. A worse error was that due to night-effect. At night, errors of 40° could be obtained if the distance exceeded 75 miles. Sudden
errors were also obtained at sunrise and sunset. These varied from instant to instant and could not be calibrated. Fortunately, this trouble was not present for short distance work and such long distance bearings were seldom required.

**Post-war Commercial Stations**

The war had little effect on high-powered commercial transmitting stations, for most of the wartime developments were confined to the small, mobile, valve transmitters. In 1920 thirty-two high-powered stations were listed, and all those on the longest wavelengths, from Bordeaux on 23 450 m (12 646 c/s) to Nantes on 6700 m (44·77 kc/s) used an arc or alternator to radiate c.w. signals at a power of 100 to 300 kW. Below 6000 m most stations used the timed-spark systems.

Although these long-wave stations were claimed to have a conversion efficiency of 50 per cent for their arcs and alternators—or 40 per cent for the timed-spark—the actual power radiated was much less. Measurements at New Brunswick, which worked on 13 600 m and was built on a sandbank, showed the radiation efficiency to be only 2·6 per cent (the radiation resistance was only 0·1 ohm). A new aerial system was installed at this station, with a number of tuned circuits connected to ground along its length, providing a phase-displacement which concentrated the radiation in one direction, and this raised the radiation efficiency to 14 per cent. The publication of these figures caused many other stations to improve their aerial/earth systems, especially the earthing which often buried many times the amount of wire that was used in the aerial.

Receivers had changed considerably during the war. Service-type two-valve amplifiers, heterodyne oscillators, tuners and filters had been incorporated to help maintain vital communications throughout each day. Before the war, when only crystal and magnetic detectors had been used, stations more than 500 miles apart had
been able to use the same wavelength without too much interference, but this large-scale introduction of valve amplifiers had made such sharing impossible. The increased number of stations had also made the multiple-tuner no longer sufficiently selective, and additional “acceptor” and “rejector” circuits had been added.

These circuits had been developed for the Royal Navy. The acceptor circuit, a small adjustable coil with a large condenser in series, was used to by-pass an unwanted signal from the aerial to earth, without passing to the receiver tuned circuits. The rejector circuit, a large coil and a small condenser in parallel, was used to stop an unwanted signal entering the receiver. The adjustment of these circuits, the normal tuner, the heterodyne oscillator, and another circuit to tune the audible note, made the setting-up quite complicated, but, once set up, the controls required little adjustment for the operating wavelength did not change. Reaction was sometimes added, but this also was a setting-up adjustment and was not under the control of the operator.

On these wavelengths atmospherics still gave trouble. They were usually called “x”s due to the early practice of putting an “x” onto the tape whenever there was an obliterated letter. Not that the experienced operator was deceived by these clicks, but the interference could be so bad that the message was blotted out. A worse trouble was the occasional bang which gave an unpleasant jar to the car, and the operator could then miss the next few letters.

Many attempts were made to tune-out the atmospherics. Cohen had shown them to be similar to spark signals which could be reduced by loosely coupled circuits such as those used for c.w. signals. But all attempts to use acceptor or rejector circuits had failed to remove atmospherics. When the “x”s were removed, so also was the signal, and removing a tuned circuit to bring back the signal also reintroduced the “x”s.

The removal of the bangs was more successful. Limiters had been introduced by the Marconi Co. using two crystals, one to detect the signal and the other, which operated only on very loud
signals, to reduce it. Wright and Turner used a valve for limiting. The valve filament was under-run so that saturation was soon obtained and louder signals (bangs) gave no increase of output. This valve limiter was only partly successful, for signals passed across the capacity formed by the wires connecting to the valve. A coil was added to this circuit to balance out the capacity but the circuit received little attention.

The largest change to the commercial station was in its organization. This was completely altered shortly after the war. In the early days the wireless station had been operated by one man. The same officer accepted the message, transmitted it, received the answer, and dispatched this to the customer. Later, as traffic increased, two men were required and both sent and received signals, operated the apparatus, and costed and routed the messages. After the war the increase in traffic made it economic to keep the operators at the equipment and to employ a clerk to accept and dispatch the messages.

The restricted number of wavelengths also forced companies to work their apparatus for twenty-four hours of the day and this necessitated working the operators in shifts. Then economics required both the transmitter and receiver to be continuously operating, instead of one or the other being used, so that one man was kept at the transmitter and another at the receiver. This made it essential for the transmitter and receiver to be on different wavelengths, indeed, to prevent interference it was necessary to house the two sets of apparatus in separate buildings which were a large distance apart. This separation necessitated telephone lines between the buildings and, logically, the office at which the messages were received and dispatched was removed to the city. The operators were also taken to the city, the key being connected by a telephone line to operate a relay at the transmitter, and the received signals passing over another telephone line to the office. This left only technicians at the transmitting and receiving stations, and their job was to adjust and maintain the apparatus.
The Marconi Co. had three transmitters at Ongar, Essex, 24 miles from the control office on the Victoria Embankment. One was used for transmissions to France, another to Canada, and the third to Spain and Switzerland. The receivers at Brentwood were 21 miles from London. Each transmitter was under the control of one man and was operated by high-speed relays direct from London.

The New-York Radio Central telegraph office, opened by President Harding in November, 1921, was some 70 miles from the transmitters at Rocky Point and 16 miles from the receivers at Riverhead: 200 kW Alexanderson alternators were installed to operate on wavelengths between 15 800 m and 20 000 m. The aerials were carried on six towers 410 ft high and spaced 125 ft apart. The design was originally for twelve alternators operating simultaneously, but this was never completed owing to its becoming obsolete in the light of other technical advances.

This separation of the transmitting and receiving apparatus had the result of making specialists of one sort or the other, with little liaison between the two groups. This had the drawback that improvements relating to both equipments were often not related to each other until both groups had spent considerable time and money in discovering the same solution to similar problems.

**High-speed Transmission**

At about this time a new method of rating the efficiency of transmitters was devised. Previously, the electrical efficiency had been used: the supply power required to provide the power to the aerial circuits was the criterion but the power actually radiated was never mentioned, for this gave a ridiculously low figure. Now it was realized that even the electrical efficiency was unimportant, for every transmitter was obliged to transmit for 24 hours per day; even if there was no traffic it sent a series of "V"s to ensure that no other station took over its wavelength. The impor-
tant factor for any station was its commercial efficiency, the maximum number of words of traffic the station could handle per day. This factor set a limit to the income of the station and had to be considered in the initial stages of the design.

Expert operators could not write at more than 40 words/min and higher speeds could only be recorded. But by this time the cable companies had developed machines for high-speed working. Wheatstone's automatic transmitter used a machine like a typewriter to punch holes in a paper tape which was then passed through another machine which keyed the line at between 100 and 300 words/min. For receiving, the morse inker had been superseded by the undulator, in which a pen drew a straight line on a tape until a signal arrived. This caused the pen to move sideways to make a notch in the line, and signals at 100 words/min could be received. Another recorder invented by McLachlan used an iron wire passing between two drums and could write at 300 words/min.

But the speed of transmission by both cable and wireless was controlled by other factors. In 1922 Nesper showed that, owing to its electrical capacity, a submarine cable was limited in its speed of working to about 35 words/min, and a wireless spark transmission was limited by the spark train frequency to about 20 words/min. Nesper used the letter L (· — ·) with a dash equal to the length of three dots and the space between the dots equal to a dot. A word of five letters required a time of 60 dots per word, and 100 words/min. was equal to 50 dots and 50 spaces per second, or a signalling speed of 50 c/s. At the receiver the high-speed machine was operated by relays and these took time to operate. A c.w. transmitter, when working on 20 000 m (15 kc/s) gave only 300 cycles of oscillation for each dot, and on such a long wavelength high speeds were not possible, for there was insufficient time for the relay to move the pen.

The effect of Nesper's book, *High-speed Radio Telegraphy*, was to stop the building of long-range spark stations, and even new c.w. stations tended towards shorter wavelengths. This, however,
raised other problems. The first was the restricted number of hours of working, for the shorter wavelengths were limited in the number of hours per day during which contact could be established, and that had to be balanced against the increased speed of working.

Shorter wavelengths also raised a problem of frequency stability. The frequency of an alternator was normally held steady to about 0.5 per cent and a transmitting frequency of 30 kc/s could change by 150 c/s when the key was pressed. This change was scarcely noticed even on a heterodyne note. But if the alternator frequency was multiplied eight times to transmit on 240 kc/s (1250 m) the change was 1200 c/s, and when an audio note filter was used the signal could be lost. Even a variation of 0.1 per cent, which was near to the limit of what was possible, caused the heterodyne note to sound 'kee-oh' or "oh-ek" at each dash, and this diverted the operator's attention from the spacing of the signals, making reception difficult.

**High-power Valve Transmitters**

The Marconi Co. owned patents for arc and alternator transmitters, but, by possessing the Fleming patent, it had a monopoly of all valve patents, so that the company was at great expense to extend the use of valve transmitters. To prove their efficiency a panel (Fig. 1.11) was built at Caernarvon to hold fifty-six MT2 valves, of which 48 were used in parallel. With an input of 16 kW, to give a current of 320 A in the aerial, the signals from this transmitter were heard in Australia. But all valves were fragile and their life, even if it was 4000 hours (six months of continuous use) was short compared with that of an arc or alternator which was expected to last for 30 or 40 years. These arc transmitters were to be obsolete in ten years, but no one was to know that at the time.

Further, to encourage the use of valve transmitters, the Marconi Co. arranged to repair any faulty valves. This normally entailed the replacement of the filament. The valves were hand made and the
parts had sufficient value to make a repair worth-while, but the great advantage of this arrangement was that the operating conditions and the causes of failure could be examined. Many filaments were shown to burn out owing to metal being evaporated from their surface, which caused the filament to become thin and reduced the emitting surface. The operator then increased the temperature to provide more power, giving increased evaporation and a more rapid burn-out. Evaporation could also take place from the surface of the anode, and to reduce this, nickel anodes were changed for molybdenum. Valves of the MT7 type, constructed like the MT2, could be used with twice as much power.

To avoid problems with d.c. machines, valve transmitters were operated directly from the a.c. supply with one transformer to
supply the filament and another to provide the h.t. supply. The valve could only oscillate when its anode was positive, or at each alternate half-cycle, so the transmission was a continuous wave interrupted at 50 c/s and also modulated by the rise and fall of the alternating voltage. This transmission could be received with a crystal receiver or a magnetic detector, without a heterodyne, but it was of no use for high-speed signalling for both the interruptions and the modulation reduced the time during which the relays could operate.

The need for a pure c.w. transmission led to the use of an additional diode valve. This diode passed current at each alternate half-cycle into a large condenser which became charged and acted as a reservoir to provide a continuous flow of current to the oscillator valve. To make the flow even smoother, a large iron-cored inductance was connected in the supply to the oscillator and another condenser was sometimes used to act as a second reservoir.

The diode rectifier valve passed current only on alternate half-cycles while the oscillator passed current on both half-cycles; so the emission from the diode filament had to be at least twice that of the oscillator. Two diodes could be used in parallel, so that a standard filament could be used, but it was better to operate these diodes on alternate half-cycles to give a more continuous supply to the reservoir condenser and keep the voltage steadier. At first two transformers were used, but later these were wound on the same iron core, giving a centre-tapped secondary winding.

Valve transmitters of this type became increasingly used. In Germany, valve transmitters of 0.5 kW were used on wavelengths of between 2000 m and 3000 m at the Koenigswusterhausen transmitter to provide all their transmissions within Europe. The Swiss station 10 km north of Berne had a 25 kW transmitter with twelve MT6 valves in parallel. This station obtained its h.t. supply from twelve MR6 diodes operating in full wave from a three-phase supply.

To overcome the Marconi Company's monopoly of valve
transmitters, other manufacturers were encouraged to develop large transmitting valves. One disadvantage of these valves was the large glass envelope, for the power dissipated at the anode had to be radiated through this glass, which softened if heated above 200°C. To reduce the dimensions, the Mullard Co. produced a 2.5 kW valve in an envelope of silica glass, the greater heat resistance of silica allowing the bulb to be smaller. The disadvantage of this valve was that it was difficult to see if a blue glow occurred but, by 1921 silica valves with ratings of 10 kW and 25 kW were being made. Similar valves were also developed in France, Holland and the USA.

**Imperial Wireless**

The improvement of high-speed long-distance communications led to a renewed demand for wireless communication to all parts of the British Empire. Comparisons were made with the Americans, who had a number of stations transmitting; with the Dutch, who were already building stations; with the Spanish, who had a scheme in operation, and with the French who had a plan to link their dominions. A committee was appointed to prepare a scheme which would incorporate all the latest developments, as well as strategic and commercial requirements, the capital and upkeep costs, and the approximate revenue from such stations.

The Marconi Co., remembering the trouble attending their earlier contract in 1912, refused to give evidence to this committee. Instead, it offered to pay for the necessary stations and to operate them for thirty years, during which time the Government would receive 25 per cent of the net profits, and at the end of the period it could have the stations free of charge.

The Imperial Wireless Committee, in its report (1920), suggested that the government should own all the stations. These should be 2000 miles apart, with an arc station at Leafield to transmit to
Cairo, and valve stations at Cairo, Poona, and Singapore which would pass messages to South Africa, India, Malaya, Hong Kong, and Port Darwin. A separate valve station would link England with Canada.

The Marconi Co. offered to erect up to five of these stations at a cost of £2 million each, and later accepted a contract from Amalgamated Wireless, Australasia, to erect a 1000 kW station at a cost of £487 000.

Actually the first year’s cost of the Leafield station, which was opened in 1922, was £36 000 against an income of £24 000. The Cairo station was even more expensive, its costs in one year being £49 000 and its income only £4700. Even then the service to Bombay had to be suspended all the summer because of atmospherics. In fact, Imperial Wireless would have remained a dream had it not been for the short-wave beam service established some years later.

Wireless for Civil Aircraft

With the coming of peace a new industry, civil aviation, was opening up. This industry had a great need for wireless, for aeroplanes were at the mercy of the elements even more than ships at sea. Pilots needed to know local weather conditions, and the conditions along the route for some distance ahead, plus any probable change of these conditions during the time of the journey. The aerodrome at which the pilot intended to land could become unusable through fog or floods, and he would need to be told, in flight, of the nearest aerodrome at which he could land. Only wireless was capable of providing this information once the flight had started.

The advantage of radio in aircraft was shown as early as 1920 when a Handley-Page Hannibal airliner, flying from Abbeville, encountered fog while still many miles from Lympne. The control
officer told the pilot the weather was clearing and the journey was continued. Shortly afterwards the weather again closed down and this was the only flight from France to England that day.

At this time the number of aeroplanes was scarcely sufficient to make ground control of landings necessary, but it was advantageous for the pilot to report his estimated time of arrival at the aerodrome, so that sheep could be driven to one side of the runway and arrangements could be made for the dispersal of the passengers. In 1920–22, when aircraft started to fly the Atlantic, some of these were lost. Those with wireless did offer their crews some small chance of rescue, but those without wireless disappeared without trace. Even with wireless the chance of rescue was small, for the nearest ship could be some days’ sailing away.

In 1920 there were seven recognized aerodromes in Britain. These were operated by British Commercial Airways in conjunction with the Air Ministry. They were staffed by ex-RAF personnel and were equipped with ex-RAF radio equipment: a receiver and a 250 W valve transmitter which operated on 900 m and 1200 m. The h.t. for the transmitter was supplied by a motor-generator, driven from a 12 V accumulator, which was kept charged by a petrol/electric set. These stations had a range of 400 miles on c.w. and 100 miles on r/t.

The station maintained a constant listening watch on 900 m for messages from aircraft in the air, most of which were r/t direct from the pilot. By 1922, radio had been fitted to all aircraft which carried passengers more than 100 miles in one hop, or more than 15 miles across the sea. Some airliners carried an operator who could transmit messages for passengers. To occupy their time, the radio staff were instructed to provide weather reports to the Meteorological Department of the Air Ministry. At that time, weather forecasting relied to a great extent on the rapid collection of barometer and thermometer readings, plus information on cloud formations in various parts of the country. This information was sent to the Air Ministry by a special code and a forecast of the
conditions along the main air routes was broadcast on a wavelength of 1680 m.

Aircraft wireless equipment was usually installed in the tail, well away from the pilot, and all adjustments were carried out before the aircraft left the ground. A Bowden cable attached to a switch in the cockpit operated the send/receive switch and sometimes a second control permitted small adjustments of the receiver tuning. H.T. for the transmitter was obtained from a small generator on one of the wings driven by a small propeller when the aircraft was in flight.

Microphones for r/t were made very insensitive, for in noisy surroundings the operator would shout to hear himself above the general noise level. He not only made himself hoarse but he overloaded the modulator valve and rendered the transmission unintelligible. One method of overcoming this was to provide "sidetone", the telephones being connected across a capacitor connected in the earth lead. The lower side-bands of the transmission produced a slightly larger voltage across the capacitor than the upper sidebands, and by suitably choosing the capacity a clear signal was heard. Another method was to use the receiver a.f. stages to amplify the microphone signals before they passed to the modulator. The operator was then able to hear the sounds without disconnecting his telephones from the receiver.

Direction finding was not easy in aeroplanes. The Bellini–Tosi aerial was tried in large biplanes, one loop passing around the nose and tail and the other passing along the wings, but the metal of the petrol tanks and engine caused large errors in the bearings. Loop aerials were tried but the small signal made it very difficult to find the position of zero signals. In practice, this zero was often completely lost in the general noise level and interference from the aircraft's ignition system.

A novel form of loop, the crossed-frame system invented by J. J. Robinson, used two loops which were rotated together, a switch reversing the connections to one of the loops. Normally
different levels of signals were heard as the switch was reversed, but when no difference was obtained, one of the loops had to be receiving a zero signal, or the loop was at right-angles to the station.

Even a ground station found it difficult to obtain a fix on an aircraft owing to its speed. At speeds of 60 m.p.h., the aeroplane had flown some ten to fifteen miles between bearings. Croydon, Fulham and Lympne were connected by telephone so that they could take simultaneous bearings, but even then the radio operator had to know the distance and direction travelled between sending and receiving the bearing. This difficulty was, however, turned to advantage in the aircraft, for two bearings could be taken from the same station while the machine was flying steadily on a definite course. Two divergent lines were drawn from the station, at the angles registered, and then a third line was drawn across these at the flying angle for the distance covered between the two bearings. Where the third line fitted between the other two gave the positions at which the two bearings were taken.

Radiotelephones

The only other wartime development for which the commercial companies saw any future was the r/t transmitter, which did not require a skilled operator. Apart from its use at sea and in the air, it was demonstrated for providing normal and emergency communications for both private and industrial users. In 1919, when it was anticipated that a strike of railway workers would cause the telephone lines to be cut, the Marconi Co. provided seven r/t sets at the main stations of the Midland Railway for emergency communications. In America, a forest fire destroyed 90 miles of telephone lines, interrupting the cable service for a week, but communications were resumed after only one hour by using an r/t set floated on a raft in the middle of a lake.

High-powered r/t transmitters were also designed. In March, 1919, the Marconi Co. used a 2·5 kW transmitter at Ballybunion,
Ireland, to broadcast speech on a wavelength of 3800 m. This transmission was heard by a number of ships at sea, and reports of its reception were obtained from a large number of amateurs, even from America.
CHAPTER 2

Amateur Wireless

The Amateur

Amateurs have made a hobby of wireless ever since its invention. Much of the original work was carried out in the amateur spirit of curiosity rather than for financial gain. Even Marconi claimed to have been an amateur until he started the Marconi Wireless Telegraph Co., and most of the early personalities of wireless, and many of the originators of large radio firms, began their careers as amateurs.

The Wireless Telegraphy Act of 1904 obliged the Postmaster General to grant a licence to any applicant "whose sole object in obtaining the licence is to enable him to conduct experiments in wireless telegraphy". By 1913 there were about a thousand of these amateurs in Great Britain and they formed clubs in which to discuss their hobby. One of the first of these was the Wireless Society of London, started in July 1913 in the house of R. H. Klein, with the object of wresting from the Postmaster General a charter of freedom for all amateurs. Many famous men were invited to become Vice-Presidents, and among those who served were: S. G. Brown, R. Clarke, Crookes, Duddell, Eccles, Erskine-

This club held regular meetings at which new apparatus was discussed and the theory of wireless was expounded. The first Presidential Address, given by Campbell-Swinton in 1914, included a greeting from Commander Ferrie which was received by wireless from the Eiffel Tower, written by a syphon recorder, and then projected by a epidiascope onto a screen. Reports of these meetings were printed in *Wireless World*, a weekly periodical which, up to the Second World War, was the bible of the amateur and professional wireless worker.

The early amateur station had plenty to impress the visitor. Large coils, wound on formers 12 inches in diameter and some 3 ft long occupied one side of the room, and on the other side was a bench carrying batteries of the fuming-acid type. Induction (Ruhmkorff) coils with large spark gaps, Leyden jars, the key and headphones, and a large board which carried almost every type of known detector, with switches to select the most sensitive detector to suit the night’s conditions, completed the equipment.

Amateurs listened to each other’s signals and to morse from the commercial stations. There was Poldhu, with a rich musical note on 1800 m, Clifden, with a high clear note on 4000 m, Nauen, with a coarse ploppy note on 1200 m, and loud deliberate signals from the Eiffel Tower. But the main joys were the making of apparatus and just the reception of signals over the air.

The amateur normally used similar circuits and apparatus to those

*Fig. 2.1 Early amateur station*
of the commercial companies, these being modified according to the depth of the pocket and the limitation on power by the Post Office. All the components were hand made, for there were few instrument-makers who supplied such apparatus, and what was made was very costly. A few amateurs even tried speech transmissions, using an arc for generating the carrier, but these were not very successful. The most notable of these were Grundle-Mathews and Thorne-Baker.

But all this pleasure was interrupted in 1914, when the outbreak of war brought official orders: “No person shall, without the written permission of the Postmaster General, buy, sell, or have in his possession or under his control apparatus for sending or receiving messages by wireless telegraphy, or any apparatus intended for use as a component part of such apparatus”. So the amateur packed up all his apparatus, took it to the police station, put on a uniform and went to war.

Wireless clubs had also been started in America, and in 1914 Hiram Percy Maxim united these to form the “American Relay League”, with the main purpose of relaying messages from one end of America to the other. This league continued to operate until 1917, when America also entered the war, and during this time it enrolled 4000 members. Even during the war it continued in being, though inoperative, and by the end of the war had 10 000 members—sufficient to lobby their representatives for permission to re-commence their activities. The American amateurs were operating again in 1919.

In Britain there were many men who had obtained a fair theoretical knowledge of wireless in the Services. Upon demobilization many of these wished to communicate with their friends by wireless but they found the Defence of the Realm Act (DORA) still in operation and had to wait until 1920 before permission was granted even to install a receiver. Meanwhile, they formed wireless societies in many towns and talked wireless and wartime experiences to anyone who would listen.
Amateur Receivers

In 1920 DORA’s skirts were lifted a little but before the amateur could buy or put together apparatus it was necessary to fill in the appropriate forms, and buy a licence (costing ten shillings) from the Post Office. The old amateur was then able to claim his apparatus from the police and the newer amateur started to assemble a receiver. After satisfying nostalgia, most of the old amateurs also started to build new apparatus, for conditions had now changed. By this time building was easier. There was a source for the supply of components and other apparatus in dealers in ex-government surplus equipment. Most of this was in good condition and prices were low.

Three parts of the joy of being an amateur was still in building apparatus; indeed, most of the ex-government equipment was unsuited for amateur use, being made for operation on the short wavelengths used during the war. But any man who was handy with tools could dismantle this apparatus and use it in published designs. So small was the sale of new components that the dealers starred these items in their lists, all other items being government surplus. Of these dealers a special mention should be made of Mrs. Kate Raymond, of Lisle Street, London, who fostered the interest of many young amateurs.

The criterion of a receiver was always the number of stations which had been heard on any night, or the most distant station, regardless of its power, that had been received. The results achieved with the receiver depended mainly on the operator, but, strangely enough, it was always the apparatus which was praised (reflected glory on the builder) or the atmospheric conditions which were blamed for the results.

Apart from ships at sea, on 300 and 600 m, the most useful wavelengths were those occupied by the commercial stations, 1500 to 30 000 m, and the amateur’s tuner had to cover the whole of this wide band. This was an entirely different requirement from
that of the commercial tuner which was required to remain on one wavelength, or a very small band of wavelengths. The amateur usually made two tuners, one for the wavelengths between 300 and 2000 m and the other for the longer wavelengths.

A typical short-wave tuner consisted of two single-layer coils wound on wood or ebonite formers about 10 in long. One former was 5 in in diameter and the other 3 in, so that one could be moved inside the other, the whole unit being mounted on a baseboard 20 in. × 8 in × \(\frac{1}{2}\) in and 5 in. high. After winding the two coils, which used about \(\frac{3}{4}\) lb. of wire, they were soaked in shellac varnish and baked to keep out moisture. The two coils were connected in series, and tappings were looped out of the larger coil and connected to a stud switch to provide a coarse selection. Fine tuning was obtained by sliding one coil inside the other to vary the mutual inductance.

For the longer wavelengths a separate, larger, coil was connected in series with this tuner. This loading coil was often 5 in in diameter and 2 ft long and much ingenuity was displayed in reducing the size of this coil. Multilayer windings could make it much smaller, but the capacity between the turns reduced the signal strength and the selectivity. Banked windings gave less capacity but they were tedious to wind and the same results could be obtained by layer-winding in small sections which were separated by paper or ebonite cheeks.

Other types of coil were the "pancake" or "basket-weave" (Fig. 2.2) or one wound on a small wooden ring which had an

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**Fig. 2.2 Pancake or basket-weave coil**
odd number of nails (9 to 15) around its periphery. The wire was wound in and out of the nails so that successive layers crossed each other; the winding was then shellacked and baked, and the nails and former were removed. A number of these coils could be connected in series for a long-wave coil.

Another compact coil, of low capacity, was the "honeycomb" or "lattice" coil. Two rows of nails were used on a former about one inch long, and the wire taken backwards and forwards between the nails (Fig. 2.3). With 15 nails on each side, the wire was taken from nail 1 across to nail 7 on the other side, and then
back to nail 15, then across to nail 6 etc., so that 15 layers were required to bring the wire back to nail 1 again. About 100 turns were wound for 600 metres and 250 turns for 3000 metres.

Some amateurs purchased ex-government tuners which contained formers and variable condensers. Variable condensers (Fig. 2.5) did away with the necessity for switches and tappings on the coils, or the need for coils which could be moved on their mountings. Previously, few of these condensers had been used, for the plates had to be hand-made and after the semicircular vanes had been cut from the sheet each of them had to be flattened, which was not easy: now a 0·005 μF condenser, bought for £2 10s, could be dismantled and made into a number of 0·001 μF, or 0·0005 μF condensers. The biggest difficulty was to match the thickness of the collars and washers which spaced the vanes apart. Later vanes were purchased for 6d per pair and assembled as required.

When the tuner was made it was tested with a crystal detector and a pair of telephones, both government surplus. The only other crystals were natural ones. A holiday in Wales could result in a pocketful of galena chippings but these had only a few sensitive spots. A small ebonite panel was made on which the crystal cup, and the cat’s-whisker, were mounted together with terminals for the tuner, aerial, earth, and the headset.
The aerial could be a single-wire “L” aerial which was limited by the Post Office to 100 ft including the lead-in, but a twin-wire aerial was recommended because it could have 140 ft of wire which, giving greater capacity, required fewer turns on the tuner. The amateur purchased 150 ft of phosphor-bronze wire for 13s 6d, four green insulators (1s 8d each) and two ash spreaders (3s 6d) and the whole aerial was slung between the roof of the house and a tree; a pole was not government surplus and cost more than the rest of the aerial.

A buzzer was often constructed to provide a signal when searching for a sensitive spot on the crystal. The buzzer was made from an electric bell with the striker arm cut off and a small piece of rubber inserted between the spring and the armature to raise the pitch of the buzz. The spark at the contact gave a strong enough signal without any connection to the buzzer.

After experimenting with various tuners and crystals the amateur had to keep up with the rest of the club by using a valve. This required careful consideration; in districts near a Government receiving station, it was not even permitted. An ex-government French valve cost only 12s 6d, but one had to add to this the cost of an accumulator and an h.t. battery. Then there might be the cost of a trip to London. Valves were sold at the buyer’s risk, and even if one trusted the dealer, a filament was very fragile. Meanwhile, an ebonite panel was made and four valve sockets, a rheostat to vary the filament current, and terminals for the l.t., h.t., tuner, and headphones were mounted on it. Next the trip to London, where the filament was seen to light: the amateur returned home, inserted the valve in its sockets and turned up the rheostat—it lit, and everyone sighed with relief. The valve was only tested as a diode on the first night and after that it was carefully removed from its socket, rewrapped in cotton wool and placed in a safe place.

The purchase of an h.t. battery was always delayed until the last minute, for dry batteries deteriorated even in store. Actually the amateur usually bought six 4·5 V flashlamp batteries and connected
these in series to provide the h.t. supply. These were likely to be fresher than an h.t. battery, even assuming that one could be bought locally.

Having obtained an h.t. battery the amateur was able to make experiments with leaky-grid and anode-bend detectors. But in a very short time a reaction coil was connected in series with the telephones and placed inside the tuning coil. The first attempt usually found the coil connections to be reversed, and signals decreased instead of increasing, but this was soon cured.

The next trouble was less easy to overcome. The change of position between that giving the loudest signals and that for a prolonged howl was very small, and the art of adjusting the reaction coil to the loudest signal had to be acquired. Many devices were invented to make this control easier, for, in just the correct position, a large number of stations were received with the headphones placed on the table.

The next stage was the purchase or construction of a transformer. These were available from government surplus stores but were

*Fig. 2.6 Receiver units made for amateurs by W. G. Pye (1922).*

*Note the "hedgehog" transformer on the left*
dearer than a winding and a bunch of iron wires. The winding had thousands of turns on a cardboard former with each layer separated by a paper tissue to make a neat winding. The iron wires were threaded through the former and bent back to meet as a closed loop. The appearance of the complete transformer was like that of a hedgehog. This transformer was used to couple the valve to a crystal detector, but the amplification of the valve was disappointing, being little better than the leaky grid without any reaction. Attempts to add reaction to this circuit were also not successful, and usually, after a few nights, the amateur reverted to his leaky-grid-cum-reaction receiver until he could afford a second valve.

The addition of the second valve did not require so much thought for it could be run from the same batteries. Separate panels were used for each valve to allow greater flexibility when making experiments. Each valve had its own rheostat so that the filament current could be reduced when signals were loud. The telephones could also be connected to the first valve when required, again saving filament current, which was a big consideration in the days of bright emitter valves taking 0.75 A.

Amateurs also experimented with resistance/capacity-coupled amplifiers, which presented few difficulties for the resistors were all home-made. Either a lead pencil was rubbed into a groove filed in a piece of ebonite, or blotting paper was soaked in Indian ink until the resistance was reduced to the required amount. Usually, a number of these resistances were made, and were sorted to their values by means of a megger. Those amateurs who could not afford such a meter would take their resistors to the club where one of the members would measure them. A few resistors were to be obtained from the dealers but these were rarely much better than the home-made ones. The resistance/capacity-coupled amplifier had little attraction for the amateur as its amplification was so much lower than the transformer coupling. These experiments were therefore not prolonged.

Some amateurs tried to use the valve as an r.f. amplifier, but the
anode coils had to be widely separated from the aerial tuner to prevent stray reaction coupling. Tuning the coils usually gave uncontrollable oscillation, and the reaction coil had to be reversed to receive any signals.

In general, the amateur found that the best results were obtained with a leaky-grid and reaction detector with a transformer-coupled a.f. stage. The only reason for using extra valves was for boasting, or hoping to find a circuit which would be stable and still amplify.

**Amateur Transmitters**

Although permission to receive signals had given fresh life to the wireless clubs, this did not satisfy them for long. Many amateurs wished to transmit and the Post Office was approached for licences. To strengthen these requests, twenty-three societies from various parts of the country became affiliated to the Wireless Society of London. This society sent a joint request to the Postmaster General which resulted in a representative of the Post Office attending a meeting and promising to issue licences to any applicant having the required qualifications. These were the ability to receive and send morse at 12 word/min, the passing of an examination in the principles of magnetism and electricity, and proof that the applicant was conversant with the theory and operation of wireless apparatus. Those amateurs who were operating before the war and ex-service operators had already passed similar tests and were deemed to be qualified.

The licence to transmit contained a number of restrictions: no licence was granted to an amateur living near a Government station in case interference was caused; the power of the transmitter was limited to 10 W input; transmissions were to be on a wavelength of 1000 or 200 m; the hours of transmission were limited to two hours per day and these had to be stated on the application form; the names of the persons with whom the amateur
would communicate had to be given, and they had to live within a radius of 10 miles of the transmitter.

Nevertheless the pre-war amateurs were soon back on the air using their old spark sets—a motor-car ignition coil and a car accumulator. The ex-Service operator, knowing little about spark sets, started to construct a valve transmitter which followed closely those he had used in the Service. There were a few ex-government 10 W and 25 W valves available and these were used with either a 200 V or 500 V supply. All amateurs used the 1000 m wavelength for the 200 m wavelength was thought to be ridiculously low. Variants of the Meissner circuit were the most favoured, the grid and anode coils being wound on separate formers using the thickest possible wire. The anode coil usually had two sets of tappings, one for tuning and the other for coupling to the aerial. Each tapping wire was threaded with ceramic beads to accentuate the danger of the high voltage.

The greatest difficulty was the h.t. supply. The filament could be run from the receiver's accumulator, but an h.t. battery did not last long when supplying 50 mA. A few amateurs were lucky enough to have d.c. electric light mains which could be used for h.t. but care was necessary with the earth connection, which could only be made through a condenser. This left all connections live to the touch.

Others, less fortunate, had a.c. lighting circuits and had either to buy two mains transformers—one for the filament and the other giving 500 V for h.t. supply, or an electric motor to rotate an ex-government aircraft generator. The latter gave a pure c.w. note instead of the rough note of the raw a.c., but it had to be interrupted so that it could be received by a crystal set.

The amateur with no mains had the worst problem. Leclanché cells to supply 200 V took up a lot of space and required constant attention, while accumulators had to be charged at the local garage, which in 1920 could be miles away. Only those who have carried a car accumulator more than a mile can appreciate this problem.
Some amateurs made a petrol/electric set, using an ex-government generator and a secondhand motor-cycle engine. This had to be run outside the shack because of its noise and fumes. The long leads gave too much voltage drop to allow the l.t. winding to be used for the transmitter valve filament, but this winding could be used for battery charging.

A double-wound generator could also be used as a motor-generator, the l.t. winding being connected to an accumulator to make it rotate, and the h.t. could be taken from the other winding. An adjustment to the brushes was usually required to prevent sparking.

One other method of providing h.t. which deserves mention was the vibrating reed system. The large secondary voltage obtained from an induction coil was applied directly to the valve anode. This system radiated a signal which was a cross between a spark and a c.w. signal. Indeed, its only merit at this time was that it was an intermediate stage between the spark transmitter and the valve transmitter when the change was being made.

The majority of the experiments owed little to theory, but enthusiasm and experience, and the attitude of trying anything once produced results. Once someone had found an arrangement which he considered better than the previous one, he told everyone at the club and they quickly tried the new arrangement, circuit, or component, retaining it if they thought it was better and returning to the former set-up if they did not. The method of assessing improvements was somewhat vague. Meters were too expensive, and their accuracy was questionable, so the criterion depended on the receipt of QSL cards. Everyone who heard a transmitter promptly sent one of these cards to the station, and by return of post received a similar card. The assumption was that the circuit which produced a card from the most distant (DX) station must obviously be the best.

Technical knowledge was not easy to come by. Three good books were available, by Coursey, Eccles, and Fleming. But these
were too mathematical for the majority of amateurs and the simplified accounts from periodicals and the talks at the club were relied on to satisfy the authorities for the examination. By the end of 1920, however, amateurs were transmitting once again.

**Music Transmissions**

Some amateurs experimented with wireless-telephony. The old arc transmitters had been discarded, for valve oscillators were more easily modulated. Here again, the amateur tried all the different methods of modulation but most of them settled down with the RAF anode-choke circuit, or the Heissing method. This had the advantage that the modulator could be built as a separate unit, and when changing from the key to the microphone no change was required to the operating conditions of the oscillator.

The licence permitted speech transmissions, but they had to be about the experiments being undertaken. Music could be broadcast, but only for testing purposes. However, many amateurs found it was essential to play a piano, flute, or cornet, to show the high quality of their transmitters, and those who were unable to play an instrument either persuaded a musical friend to assist, or used a gramophone.

The amateur's microphone was either an ex-RAF solid-back carbon microphone—damped for speech transmissions from an aircraft—or the standard pillar Post Office hand microphone. Both gave reasonably clear speech but the reproduction of music left much to be desired. When not transmitting live, the microphone was placed inside the horn of a gramophone. Such transmissions were slightly distorted by the horn—never, of course, by the wireless equipment—and improved results were obtained by removing the horn and putting the microphone on the end of the tone arm.

These speech and music transmissions, bad as they were, were greatly appreciated by the non-transmitting amateurs who had not
Fig. 2.7 6RJ amateur transmitting station (1923)
yet learned the morse code. Having a continuous carrier, they were easier to tune in than morse signals. The standard method was to resolve the modulation from the carrier. The reaction control was first advanced until the receiver was oscillating, then the tuner was adjusted to obtain a zero heterodyne note, lowering the note to the dead-space, and finally, the reaction was decreased until the receiver was just not oscillating. If the receiver was oscillating, the signals were very distorted.

While the receiver oscillated it acted as a small transmitter, and all the nearby amateurs who were listening to a transmission also heard the heterodyne notes of each amateur who tuned in to the same station. The speech or music was continuously reinforced by whistles. These were not, as one might think, a source of annoyance. Far from it. In those days each new whistle gave a sense of company. "Yes, old man, I heard you join us at 8:42 p.m."

In addition to these amateur telephony stations there were also experimental transmissions from the commercial companies. The Marconi Co. developed a 15 kW transmitter, operating on the Poldhu wavelength, from which musical programmes were broadcast. News, vocal and instrumental items were sent out for half-an-hour each morning and evening and some famous artists broadcast: Marconi spoke to Rome, and in June, 1920 Dame Nellie Melba sang into the microphone at Chelmsford. The transmissions were received by many amateurs and by ships at sea and Melba was heard in Newfoundland 3000 miles away.

An even more important application for wireless telephony was found by the teachers of Michigan Agricultural College in the USA. They realized that farmers could not leave their crops to attend school regularly and installed a telephony transmitter to broadcast the lessons to any farmer possessing a wireless receiver. To encourage reception, the College also gave weather reports, with forecasts of its effect on the crops. Then, market prices for stock, grain and other produce were added, so that stock could be kept when prices were low and delivered when they were rising.
Thus, the installation of a receiver became a paying proposition for the farmer and not merely a hobby. Later, the college added some musical items to its transmissions.

Experimental music transmissions were also taking place in many other countries. In April 1920, the Philips Co. started concerts from PCGG, The Hague, on a wavelength of 1000 m. This station used a power of 500 W, of which 75 W appeared in the aerial. On each Thursday evening amateurs closed down to listen to these programmes and good reception was reported even in the North of England. In March, 1921 the programmes were extended to two evenings per week and also to Sunday afternoons, the power also being increased to 200 W in the aerial.

In Germany, the Koenigswusterhausen station also broadcast for half-an-hour each day. At first a wavelength of 4000 m was used but this was soon changed to 2000 m so as to be heard by a greater number of amateurs. In France the Eiffel Tower, still under the Army authorities, transmitted music for two hours each week on a wavelength of 2600 m, using 400 W in the aerial.

In England, each experimental music programme had to receive a special permit from the Post Office. When the Marconi Co. requested general permission to broadcast music, in order to acquire experience to compete in foreign markets, the opposition which always attended the Marconi Co. caused reports of interference with important Service communications, and all music broadcasts were stopped in November 1920. The transmissions had been so good that most amateur transmitters had closed down in order to listen to them, and their cessation left a gap only partly filled by amateur transmissions.

But while Europe was still experimenting, broadcasting came to America with a bang. One day there was no such thing, and the next it was everywhere, its spread being accelerated by the large number of American amateurs.

In November 1920 the Westinghouse Electric and Manufacturing Co. in Pittsburg obtained a licence to broadcast information
and music. Good reception of phonograph music was reported from a wide area, and, what was more important to the businessman—and the almighty dollar—the sale of wireless receivers increased enormously. This caused the Westinghouse Co. to introduce vocalists and an orchestra into the broadcasts, and again sales increased, so the company decided to erect other stations.

In complete secrecy, a 500 W transmitter was erected and tested and it was announced that this station, WJZ, would broadcast a blow-by-blow account of the Dempsey-Carpentier boxing match for which all the seats had long been sold. Thousands of people listened to this broadcast in their homes, in dealers' shops, in public houses, and in a number of public receiving stations which had been specially erected. Reports of the achievement spread rapidly across the country. Newspapers, travellers, and anyone who could boast of having heard the broadcast, spoke of it in glowing terms.

The spontaneous enthusiasm aroused by the broadcast caused the station to introduce a daily programme of broadcasts, which started at 10 a.m. and continued until night. In the evening, special bedtime stories were told for children, and afterwards music and singing by well-known artists continued throughout the evening. Eye-witness accounts of baseball and football matches were added to the programme and by the end of the year the station had its own band. The first church service was broadcast in January 1921.

**Transatlantic Tests**

Meanwhile the British amateurs were once again grumbling—the national pastime. Non-transmitters complained of the silencing of the Marconi broadcasts, and the transmitting amateurs were troubled with jamming. Of the 150 transmitters, 50 were in London and all operated on 1000 m. If they tuned slightly off this wavelength to avoid jamming there were complaints from the
Admiralty, who operated on 1050 m, or from the Air Ministry, on 900 m. Again, almost all of them had named the hours of 8 to 10 p.m. for their transmissions, consequently during these two hours the jamming was fierce. At all other times the ether was quite empty, but they could not transmit. Then, the communications had to be to the five named stations, and none of these might be operating. At the same time, other stations could be heard making equally fruitless calls to their correspondents. The last complaint was that QSL cards were received from considerable distances but the limit of ten miles left no incentive to improve the apparatus to increase this distance.

At a meeting of transmitting amateurs it was agreed that jamming could be reduced if no one would transmit for more than 15 minutes continuously, and a 15 minute listening period in between was compulsory. This complaint applied particularly to the telephony transmitters who kept their carriers on even when they were not speaking. The older hands suggested that all new transmitters should be made to operate on 200 m, and a few even decided to try this wavelength for themselves: the change would avoid jamming, and with a 10 mile limit, what could they lose?

Invidious comparisons were made with the American amateurs, especially by those who believed that brute force, in the shape of watts, could avoid jamming. The American amateurs were allowed a power of 1000 W, and few used less than 250 W; ranges of 800 miles were common. The relaying of messages from Canada to Mexico, or from coast to coast across the continent, also caused the American amateur to have a much better operating technique than his British counterpart. Brevity of transmission was a fine art as each station endeavoured to clear its traffic. This activity was not confined to code, although code was encouraged by the American Radio Relay League (ARRL) for it reduced jamming.

By this time there were 20 000 amateurs in America and these had their own magazine, QST, which reported all the happenings in the amateur world: the amateur who made a record long-distance
contact, achieved the same distance with less power, found a new circuit, or got a new wife, all were reported in QST and read about by the “dyed-in-the-wool-hams”.

With this number of transmitting operators the jamming had been heavy, but the ARRL had solved this difficulty by dividing the country into districts. Hours, which varied with the time across the continent, were allotted to each district. Before 10 p.m. (local time) all the contacts in the same district were made, i.e. up to 800 miles, and after this hour only long-distance work was permitted; contacts were often made over 2000 miles during these DX periods.

These long-range contacts led to a desire to “raise Europe” and in December, 1920, a special test was arranged during which the ARRL invited British amateurs to listen on 200 m for signals from American transmitters. But British amateurs listened in vain for them. Some weak signals were probably heard but the oscillations from other British listeners drowned those from America before a call sign was heard and the station positively identified. This failure was considered by the Americans to be due to the poor handling of indifferent receivers, and, when organizing similar tests for the following year, they decided to ensure success by sending over a typical U.S. amateur, Paul F. Godley, together with typical American amateur apparatus.

On his arrival Mr Godley gave a lecture to the Wireless Society of London in which he reported that during preliminary tests, organized to select the transmitters to operate on the test nights, a Georgian amateur’s valve transmitter was received from a distance of 2450 miles, a Chicago spark station was reported from France, and a station in New Mexico had operated a morse inker in New York for five successive nights.

During his talk Mr Godley expressed surprise that so many British amateurs worked on 1000 m when they had the alternative of 200 m. He stated with conviction that most American amateurs would have chosen the shorter wavelength if only because the
aerial efficiency was so much higher. He compared the power radiated by a 100 kW transmitter working on a very long wavelength, and an aerial efficiency of only 4 per cent, with an amateur 1 kW station on 200 m when the aerial efficiency could be 60 per cent.

Mr Godley’s typical amateur station, 1 BUG, at Ardrossan in Scotland, incorporated the most advanced ideas for a short-wave station. The transmitter used four valves, one as an oscillator and three to amplify the power of these oscillations. These were fed to a T aerial having an eight-wire cage, 100 ft long and an effective height of 75 ft. In addition to the earth connection, he used a counterpoise of radial wires 20 ft in diameter and supported on 8 ft high posts, similar to those for the Lodge aerial. A total power of 988 W was converted into 588 W of r.f. power of which 250 W were radiated.

Unfortunately few amateurs were notified that this station would be operating and many wasted time listening to this station instead of those in America. However, five American stations were heard with their correct call signs and code words. During the free-for-all after the official hours another four American stations were logged. The most successful British amateur, Mr Burne of Cheshire, logged seven American stations using a six-valve receiver (3 r.f. det., 1 a.f.). Mr Whitfield of Birmingham logged three stations with a 2 v 2 receiver, both receivers being entirely home made.

One fact that emerged from these tests was that valve transmitters were received much more clearly than spark transmitters. This was a great shock to the older amateurs, both American and British, and many of these completely redesigned their stations within the following year. This long-distance feat of the amateur operator, using a maximum power of 1 kW, was not taken seriously by the commercial world. The professionals compared the small number of successes with the number of stations engaged and argued that the results, excellent though they were, were merely due to freak
conditions and could never be repeated for 24 hours per day, 365 days per year.

200 Metres

After the first wave of self-congratulation over the result of the transatlantic test, the amateur relapsed once more into his grumbles, with demands for longer aerials, greater power and a reduction of the licence fee. This last was a sore point for those transmitting, who were charged a fee of £1 plus £1 1s per year to cover the cost of inspection of the installation. Little inspection was done, and even this was by men who knew nothing of wireless. In any case, the amateur station was continually being changed in circuit and layout.

In reply to these demands the Postmaster General compared the power of British and American amateurs with the sizes of the two countries. As a concession he agreed to allow aerials to be lengthened, and to the use of more power in special circumstances. He also provided a new wavelength for transmitters, 440 m, but this turned out to be a “government-gift”, for shortly afterwards the 1000 m wavelength was withdrawn to prevent trouble with the Services. This exchange, of course, gave fresh grounds for complaint. However, there were a number of British amateurs who had taken Mr Godley’s remarks about 200 m very seriously. The Wireless Society of London, which now changed its name to the Radio Society of Great Britain, also decided to encourage the use of this wavelength, and it held a meeting at which many wartime circuits were discussed.

On this wavelength so few turns were required for the tuning coil that an entirely new tuner, or even a separate receiver was required. The capacity of the two-wire aerial was also too great, and shorter rather than longer aerials were required; even then only about thirty turns on a 2.5 in former were needed. The losses in unused turns of a tapped tuner caused signals to be very weak and
the separate tuner proved well worthwhile. Tuning by tapping the
turns was also useless, for a change from one turn to the next could
pass over a number of stations without the operator being aware
they existed. Variable condensers were essential for the tuner, but
these were expensive even when home-made.

The alternative was to make a variometer, with one coil rotating
inside the other, such as had been used in some Army receivers. A
second variometer could also be used in the anode circuit to
provide reaction when the two tuners were brought into tune. Such
a circuit was known in America as the Armstrong “sure-howl”
receiver (see Fig. 2.9).

The differences between the techniques for 200 m and 1000 m,
both in apparatus and operation, were so great that many of the
older men had the interest of starting again from the beginning.

Attempts to use r.f. amplifiers on these short wavelengths led to
nothing but trouble. Adding resistance to the grid and anode coils,
or winding the coils with resistance wire, were of no use. Round
and Latour had patented r.f. coils wound on iron cores which gave a
small coil with little stray magnetic field. The losses in the iron
also damped the circuit to help stability, but this was of no use on
these short waves. Nor was the method of stabilizing the amplifier
by using a potentiometer to bias the grid positively, so that grid
current damped out the oscillations. Edes showed that grid current
cased the valve to detect, or to amplify only one half of the signal
and to remove the other half. In a multivave amplifier, the half of
the signal which was amplified by one valve was flattened by the
next, so that the resulting amplification over a number of stages
was nil.

Another difficulty arose when the receiver was required to tune
to 200 m and 440 m and all the wavelengths above 1000 m.
In the simple receiver lattice-wound coils were mounted onto plugs
so that they could be interchanged, but in an r.f. amplifier this
meant changing six or more coils. Burbury halved this number by
winding two coils on a small former which was fitted with four
pins to fit a valve holder, but even then the number to be changed was too many.

Small coils and careful positioning reduced the magnetic feedback, but this still left the capacity feedback between the grid and anode circuits which was present even when the leads were kept well apart and at right-angles to each other. Whenever possible the dielectric was reduced, slots even being cut into the panel between the grid and anode pins. But when the base of the valve was removed to reduce this capacity, there was still the pinch of the valve where the leads were close enough to provide capacity. Round had patented the V24 valve in 1916 to reduce this capacity, but these valves were not obtainable from government surplus. The valve had the normal electrode structure but this was mounted in a small glass tube with two caps at the ends to support the filament, and caps at the sides to carry the grid and anode (Fig. 2.8). The valve was mounted on a panel by clipping it into four metal brackets to which the connections were made.

Scott-Taggart advocated the use of resistance-capacity coupling for r.f. amplifiers. The voltage developed across the resistance did not vary with frequency and while the gain was low, it was comparable with that from a tuned amplifier after this had been

Fig. 2.8 - Low capacity valves: left, Type Q (1916); right, Type V24 (1919)
stabilized. In addition the RCC amplifier was compact and had little wiring to give unwanted reaction. But, apart from the reduced selectivity, these amplifiers were not completely stable, and signal strength was lost owing to the r.f. passing through stray capacities instead of through the resistance. Still, Beauvais and Brillon did show that by reducing the stray capacities it was possible to obtain amplification on 200 m using an RCC amplifier.

All these difficulties caused most amateurs to give up any attempts to use r.f. amplifiers and to rely on the detector-cum-reaction circuit. Even this had its difficulties. Hand capacity caused the tuning to change whenever the hand was moved near the tuning condenser. One method of tuning was to move the hand, or a finger, to a position which gave the loudest signals, and then to hold it there until the station transmitted its call sign. But even moving the body slightly to ease cramped muscles could cause the station to be lost and never found again.

The control of reaction was also difficult. Swinging-coil reaction was quite impossible, for not only did a movement of the coil cause a change of tuning, but a movement which made the set oscillate required a much larger movement backwards to stop the oscillation, and the point of "just not oscillating" was almost
Fig. 2.10 Hartley circuit

Fig. 2.11 Colpitts circuit

Fig. 2.12 Weagent circuit
impossible to obtain. Using long handles to ease the adjustment gave no improvement of this backlash.

Two new circuits had been devised for these short wavelengths: the Hartley circuit (Fig. 2.10) used a centre-tapped tuning coil and the Colpitts circuit (Fig. 2.11) used two variable capacities to tune the coil. In both circuits the coil was connected between the anode and grid. The Colpitts circuit with its two expensive condensers was ignored by amateurs, but the Hartley oscillator was extensively used for transmitters. A wartime circuit by Weagent (Fig. 2.12) used the tuning coil and condenser in series with the aerial, and connected the detector across the condenser, the reaction being coupled to the aerial coil. An alternative was to connect the detector across, the coil and to vary the capacity for reaction. For receiving, a second condenser was added to the Hartley circuit to by-pass some of the r.f. from the tuned circuit to keep the set just off the oscillation point.

All these circuits required a slight adjustment of the tuning condenser each time the reaction was changed, but in June 1921 Reinartz (1 XAM) produced a circuit which could be taken into and out of oscillation without upsetting the tuning (Fig. 2.13). It

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*Fig. 2.13 Reinartz circuit*
also required no change of the aerial and reaction tappings over a wide range of wavelengths. The reaction coupling used a combination of coil and condenser, the feedback through the capacity increasing with the frequency and that through the coil decreasing to keep the feedback constant. So easy was the setting of these controls that a c.w. signal on 200 m could be tuned to any desired heterodyne note, which was quite impossible with all former circuits. A graph could also be made of the condenser settings for any required wavelength.

**Broadcasting**

Although amateurs continued their demands for music transmissions, these were always met by opposition from the Services. Permission was granted to the Marconi Co. to broadcast a short programme in aid of St Dunstan’s Hospital, but general permission for broadcasting was refused until the Postmaster General had good evidence that such programmes would be welcomed by amateur listeners. This caused the Radio Society of Great Britain, acting on behalf of its 63 affiliated societies and 3000 members, to petition the Government for regular telephony broadcasts from a high-powered station, on a definite wavelength for calibration purposes, and to include matters of interest to amateurs. The Marconi Co. expressed its willingness to broadcast such programmes but the Postmaster General only gave his permission for the calibration signals and withheld permission for music broadcasts.

A deputation to the House of Commons in January 1922 produced an authorization for the Marconi Co. to include 15 minutes of telephony within a half-hour weekly programme. Even then a three-minute break was required after each three minutes of transmission so that the station could listen for Service transmissions. The Marconi Co. was quick to take advantage of this, and an
Fig. 2.14 (Above) Station 2MT transmitter (1922). (Right) A 1922 broadcast concert from 2MT (the singer was Nora Scott)
experimental station, 2MT, commenced operation from Writtle on 14th February.

Station 2MT (Fig. 2.14) was a lash-up affair run in the off-duty hours of the experimental staff. The input power was 250 W, which gave about 100 W in the aerial on a wavelength of 700 m. The h.t. was obtained from a 4 kV transformer, rectified in full-wave, and the valve filaments were run from accumulators so that no hum was superposed on the vocal modulation. A normal P.O. type microphone was used, modified by the addition of a small cone over the mouthpiece to collect sounds from a wide angle.

The engineer-in-charge was a young man named P. P. Eckersley who had a fund of spontaneous humour and gave to the world all the fun of the Marconi works. Almost every amateur listened to these transmissions and many other people made, or purchased, receiving apparatus. During April and May 1922 the numbers of licences for receivers increased from 7000 to 10 000 and the increased Government revenue from these fees made a strong case for the continuation of transmissions.

Unfortunately, chaos was reigning in the American broadcasting world. The success of the original broadcasts by the Westinghouse Co. had caused demands for broadcasting in every city and starting with the addition of eight stations in September, there were 90 stations broadcasting at the end of 1921. In January 1922 there were 26 new stations, 14 in February, 27 in March, 88 in April and 99 in May. A Radio Show in New York City, which itself had 18 stations operating, was attended by thousands, magazines appeared on all bookstalls, and new radio companies were formed overnight to sell or make receivers.

The demand for receivers was beyond all expectations. In one large store the sales of a newly created radio department exceeded that of any other. It was estimated that every fifth house in Pittsburg had a receiver, and that the total number of listeners was 600 000. The demand for receivers, and components to make them,
greatly exceeded the output of the manufacturers and many bootleg companies were formed to copy the designs of the well-known firms and to sell at slightly lower prices.

About 15,000 dealers sold radio, and manufacturers could only supply a portion of their orders, so each dealer ordered more than he required. Then summer started and sales fell off, the dealers cancelled their outstanding orders and the manufacturers, new and old, were left with large stocks of components and no cash to pay for them. Then both reduced their prices to obtain cash. The new firms sold apparatus at a quarter of their list price, and the older firms sold for almost nothing. They also kept production running in order to be ready for the autumn rush. It was a long summer, however, and trade picked up very slowly in the autumn. Many firms failed and others, their credit weakened by the crashes, were unable to hold out. The strain was heavy and even those who were able to stay in business made little profit from it.

The demand was not only for receivers. Transmitters were also wanted by newspapers, shops, department stores, and other business houses who began to realize the advertising value of broadcasting. Actually the first commercial advertising programme was not broadcast until August 1922. No manufacturer had expected a demand for transmitters and no arrangements had been made to meet one. Many amateurs filled the gap by selling their knowledge, and building and operating these stations.

It was soon found that the expense of running a broadcasting station was very heavy. Only companies like large stores, who could charge these expenses to advertising, could afford to operate a station. The Western Electric Co. and the Westinghouse Co. only sold transmitters to such firms, but smaller firms acquired stations and then had to sublet part of the equipment or share part of their transmitting time.

A further problem was caused by the shortage of wavelengths. Might, as measured by aerial power, was right, but this did not answer the problem of having another station, even if weaker,
always in the background of the programme. The US Government produced some order out of this by making stations share wavelengths, and allowing some stations to transmit only for so many hours each day. This last arrangement worked surprisingly well, and stations followed one another on the air with a clockwork regularity. The ARRL also helped by stopping all amateur transmissions on the broadcast wavelengths until after 10 p.m.

In Britain the success of the transmissions from 2MT caused other applications for permission to broadcast speech and music. In March 1922, Metropolitan-Vickers requested permission to broadcast in the North, and within two months twenty other applications were received from manufacturers. But while the Postmaster General conceded that regulations could be made to prevent chaos, he was still hesitant to permit broadcasting. In fact, it was suggested that only the thought of the revenue from licences tipped the balance in its favour.

On 4th May 1922, the Postmaster General announced that broadcasting would be permitted with a maximum of eight stations, each with a power of 1.5 kW and operating on wavelengths between 350 and 400 m. The stations would transmit between 5 p.m. and 11 p.m. each night and at any time on Sundays.

As a foretaste of what was to be expected the Marconi Co. broadcast the Carpentier-Lewis boxing match. It also changed its wavelength to 400 m so that amateurs, and manufacturers, could obtain experience of receiving signals on this wavelength. The time of transmission was also changed to 8 p.m. so that more people could hear the broadcasts. In this way the idea of broadcasting was sold to the public before the service commenced. This was as well, for the start of broadcasting was delayed until the following November by arguments among its sponsors.
CHAPTER 3

The British Broadcasting Company

The Start of the Company

The Postmaster General’s announcement that eight stations would be licensed for broadcasting found about two dozen radio manufacturers who were prepared to establish one of the stations. But none of these firms was prepared to share “its” station with anyone else. Also the Marconi Co. wanted to build all the transmitters—“It was not going to allow anyone to use any of its 152 patents, and no station could be built without them”. The Postmaster General wanted all the licence fees; and to prevent competition with the newspapers, he prohibited any advertising. The arguments which took place, the bluff and counter-bluff, the way the whole scheme nearly foundered, have all been told elsewhere. Suffice to say it took six months of hard bargaining before all these firms agreed to combine to form one broadcasting organization, the British Broadcasting Company registered on the 15th December 1922.

To prevent any form of monopoly the Postmaster General insisted that any manufacturer of radio equipment should be allowed to buy shares in the company. These £1 shares formed the capital of the company which was to cover the cost of erecting the stations. The running expenses, electrical power, replacement parts, and rent—and, quite an incidental, the cost of hiring artistes
for the programmes—had also to be found, and methods of financing these expenses entailed more hard bargaining. Finally, the Postmaster General agreed to allow half the licence fees to go to the company, who would meet the rest of these costs by a tariff on the receiving apparatus which was to be sold.

To ensure that every manufacturer bore his share of the cost it was agreed to stamp all receiving apparatus with the letters “BBC”, and only people using such apparatus were to obtain a licence to receive the programmes. To prevent foreign firms selling apparatus without contributing to the costs, the Government agreed, for one year after the start of broadcasting, to restrict the licensing of receivers to those of British manufacture. Everyone appeared to have forgotten that a licence was required before apparatus could be purchased.

The Marconi Co. agreed to allow members of the British Broadcasting Company to use its patents upon payment of reasonable royalties, and a deposit of £50, and to help manufacturers to design receivers they installed a transmitter in Marconi House, London.

It was pointed out that the whole scheme could fail if the reception of the programmes was marred by jamming or the howls from oscillating receivers. To prevent such troubles the Postmaster General forbade all amateur transmissions on 440 metres during the broadcasting hours; at the same time he ruled that no receiver having reaction should be used during these hours. Second thoughts allowed reaction provided no oscillations could pass into the aerial. The construction of receivers was also to be such that changes to the circuit which might cause oscillation were difficult to make. The Postmaster General even agreed to type-test the receivers sold under the BBC stamp. These were tested for oscillation both when fitted with different valves and also when the h.t. battery voltage was increased by 30 per cent. After a receiver was given a “Type-number”, no change of the design was allowed without a retest by the Post Office engineers.

Such a lot of work went into this planning and most of it was for
nothing. The moral is, I suppose, "Never make rules which cannot be enforced". The major factors in this undoing were the amateur and the boy-next-door, who had not been considered. These two short-circuited all the plans.

In October 1921 an All-British Wireless Exhibition was held in London and, contrary to all expectations, this Show was packed out. Almost every firm in any way connected with wireless was represented, and their stands were surrounded. One red light that might have been seen was the crowds of young boys surrounding the stands of the component makers—most of these were considering the making of a receiver. During the Show the Prince of Wales broadcast to the Boy Scouts and, thanks to amateurs, this was heard in most parts of the country—a second red light?

The First Stations

The first stations of the Company were built by three firms each to its own design. The London station, 2LO, built by the Marconi Co. to operate on a wavelength of 360 metres was officially opened on 14th November 1922, a month before the Company was registered. The Birmingham station, 5IT, which was built in London by the Western Electric Co. (STC), started transmitting on 15th November on a wavelength of 420 metres. It was moved at short notice to the Witton works of the General Electric Company in order to broadcast the results of the General Election. After only one hour's testing it operated from 5 p.m. till 1 a.m. giving the results as they arrived. The Manchester station, 2ZY, designed by Metropolitan-Vickers (GEC-AEI) at Old Trafford, was opened a few days later using a wavelength of 385 metres.

2LO was the most elaborate of these stations and consisted of four panels, power supply, oscillator, amplifier and modulator, each with a metal frame and plate glass sides so that one could see the components (Fig. 3.1). The power was obtained from the d.c. mains, via duplicate motor-generator sets each with a 10 h.p.
motor to drive a 6 kW, 500 V, single-phase, 300 c/s, alternator; arrangements were also made to change over to an auxiliary supply if the mains failed. The first panel contained a step-up transformer and two valves to rectify its output in full-wave to provide 10 kV. This was smoothed by condensers and an iron cored choke to give less ripple than would have been obtained from a d.c. commutator machine. The second panel contained the oscillator circuit, and its output was taken into the third panel where the power of the oscillations was amplified before being coupled to the aerial: inside this panel was also the iron-cored choke for Heissing modulation. The fourth panel carried the modulator valve and the sub-modulator stages. The filaments of the rectifier valves were heated by a.c., but all the
other valves were heated by accumulators. A T aerial was used, consisting of two four-wire cages, each 100 ft long, supported 50 ft above the roof (Fig. 3.2). The building had a lead roof and this was bonded to the steel framework, and the electrical conduit in the building, to form an earth connection.

The Birmingham transmitter contained two panels: one for controlling the duplicate motor-generators and the other containing the oscillator and modulator stages. The oscillator was tuned by a variometer connected between the anode and grid of the valve, and another coil coupled this to the aerial. Two other features are worth mentioning: its valves had oxide-coated filaments, and the grid bias was obtained from the voltage across a resistance in the negative supply. The valve current flowed in this resistance and any increase of current gave more bias, so that it was self-regulating.

The Manchester station used four Mullard 500 W valves to supply 750 W into the aerial. The transmitting panel was made by the Radio Communications Co. but all the experience of the American Westinghouse Co. was available to Metropolitan-Vickers for this installation.

*Fig. 3.2 Aerials for the 2LO transmitter at Marconi House (1922)*
With the opening of these stations, 2MT closed down and P. P. Eckersley joined the BBC* as chief engineer. Many amateurs also joined the staff. They were forbidden to transmit during the broadcasting hours, and decided that if someone was going to put current into an aerial during these hours they might as well be the ones who did it.

The studios of all three stations were located in rooms as free as possible from outside noises. To prevent reverberation blurring the transmissions, the floors were covered with thick carpets and the walls and ceiling draped with sound-absorbing materials. The bell was removed from the telephone so that this would not interfere with the programme and a signal lamp installed instead. Lamps were also used to warn the people in the studio that the microphone was being connected to the transmitter; the lamp was first flicked-on to warn people to stop talking and then left on all the time the microphone was connected.

A surprising number of artists were found to be very nervous of the “invisible audience” and became “microphone-shy” in the dead silence of the studio. A room had to be provided for them while they were waiting, and a member of the staff had to keep them talking. It was also found that too much blanketing of the studio caused the brilliancy of the musical sounds to be spoiled, and much experimenting was necessary before the correct amount of damping was found.

But, by the terms of the licence, experimental testing could only be made outside broadcasting hours and the majority of these tests were undertaken after close-down, or on a Sunday. Many of the listeners waited after the official closing for the carrier to come back on the air, and afterwards wrote to the station to report on the tests. The Manchester station also established a listening station at Hale, seven miles away, so that the signal strength and quality of the radiated signals could be monitored. This station installed a

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* In this book the abbreviation “BBC” is used for British Broadcasting Company only.
special connection board so that various types of microphone could be tried with different types of programme. It was also found that there was a best distance between the microphone and artist, and this varied with the voice or instrument being played. A large number of experimental transmissions were required before these distances were established.

The range of frequencies required for music made special microphones necessary. In most of these the diaphragm was heavily damped to prevent resonance on some particular note, but this damping lowered the efficiency of the microphone and a three-valve amplifier was needed between the microphone and the sub-modulator stages. This speech-input amplifier was installed in a small room outside the studio and a telephone earpiece connected across the output of this amplifier monitored the programme on its way to the modulator. A control was added to allow the level of the signal to be adjusted, for a weak signal gave a low level of modulation and poor signals at a distance, while too loud a signal could cause the modulator valve to be overloaded. An average modulation level of 30 per cent was usually considered to be correct.

**Simultaneous Broadcasting**

These three stations had barely settled down when they were joined by Newcastle (5NO) on 400 m in January, 1923. Cardiff (5VA) on 395 m was opened in February, and Glasgow on 415 m in March. Reports of good reception were received from all over the UK and Europe; 5IT was even received in Canada. Transmission was so good that the programmes from Newcastle and Manchester were heard as a background to each other and the wavelength of the latter station was changed to 353 m to prevent this jamming.

Broadcasting was immediately popular. New licences were issued at an every-increasing rate: 3000 in November, 9000 in December, 25 000 in January, and 30 000 in February, 1924, to give a total of 90 000 licensed listeners. But despite this, the revenue
barely equalled the ever-increasing expenses. The highest cost was that of programmes which was greatly in excess of that originally envisaged, and when the income was only from licences and the tariff on receivers, every endeavour had to be made to increase the number of listeners. To this end, the BBC’s engineers were given one aim—to enable everyone in Britain to hear the programmes with a crystal receiver. This remained the guiding principle for a number of years.

To stimulate public interest a private line was connected to Reuter’s News Agency so that the latest news could be broadcast. Another line to the Greenwich Observatory provided accurate time signals, in the hope that these would cause every clock-maker and repairer to install a receiver. A number of unusual broadcasts were also organized: in January 1923 the London transmitter “relayed” along the telephone line a performance of The Magic Flute from Covent Garden which was received with such enthusiasm that other operas soon followed.

The success of this relay led to the relaying of programmes over greater distances. In March, experiments were conducted between the London studio and the Birmingham transmitter, the quality of various instruments, singers, and speech exceeding all expectations. The use of such a relay allowed two transmitters to be used to broadcast the same programme, or halved the cost of producing the programmes, and in April tests were made between London and Glasgow. Although the distance was four times as great as between London and Birmingham the quality of the sound was even better. Two possible explanations were offered for this: the London/Birmingham line was underground, and the London/Glasgow line was of thicker wire, 600 lb/mile compared with 200 lb/mile.

The next attempt was to relay programmes to all stations simultaneously. In May, simultaneous broadcasting took place from London to Birmingham, Newcastle, Glasgow and Cardiff, and good reception was reported from all parts of the country.

The success of this relay resulted from a number of experiments
and much co-operation between the BBC and the Post Office engineers. The speech power required to modulate a transmitter was about 0.25 W, but more than this was required to be put into the line at the studio to allow for losses along the line. The power obtained at Birmingham was only about a thirtieth of that put in at London, and so a power of 7.5 W was used in the early experiments. While the listening public was delighted, the Post Office was not: its trunk system was considerably upset. All exchanges reported crosstalk, the reception of music as a background to the telephone conversations, and the BBC was requested to use much less power in subsequent experiments.

Smaller amplifiers were tried for simultaneous broadcasts with one amplifier feeding each transmitter. This gave an improvement but complaints still persisted from the telephone users, and so the BBC decided to amplify the signals at the receiving end of the line. To everyone’s surprise this gave equally good results.

But power was only part of the problem. These telephone lines had been installed for speech, and the transmission of music had not even been considered. The loss in the line varied with the frequency and the Post Office could offer no information on this. At this time the Post Office made all its measurements at a frequency of 800 c/s, which was a typical voice frequency, but even then they were not direct figures, in ohms, but were given as comparative attenuations in terms of miles of standard cable. A thin cable was said to have an attenuation of 1.5 standard-miles, meaning that at a frequency of 800 c/s, one mile of thin cable gave the same attenuation at 1.5 miles of standard cable. But at 1000 c/s the standard cable had an attenuation of 1.18 standard-miles and this reference, first to the standard frequency and then to the standard cable, made calculations very difficult.

The BBC tested many cables to find a type which gave the best transmission for all musical frequencies. They found that a loaded cable, one with small coils inserted along the route, gave less variation than an open-wire line—one carried on poles along
the side of the road—but the loaded cable gave almost nothing for frequencies above 2500 c/s, and so the BBC was forced to use the open-wire. This at least gave some high notes at the far end, and these could be amplified more than the other frequencies so that the variations were not very noticeable.

Before any simultaneous broadcasts the BBC's engineers tested a number of lines and selected the best three: the first for the programme, the second for the engineers to keep in touch with one another, and a third to provide against a fault, such as the removal of a plug at one of the trunk exchanges. (A gap in the programme from this cause was by no means uncommon.)

The BBC had to pay for the Post Office lines it used but, when every large town was demanding a station of its own, without simultaneous broadcasting the cost of providing programmes at these stations would have been prohibitive. The saving offered by simultaneous broadcasting also enabled the BBC to accede to public demand for longer broadcasting hours. In March 1923 lunch-time music was introduced, which enabled dealers to demonstrate receivers during the lunch hour. This increased their sales—and the number of licences taken out. Broadcasting also started on Sunday afternoons and evenings, with a break between 6 p.m. and 8 p.m. so that people did not stay away from church. A number of "stunt" broadcasts were also made: a speech by Rutherford to the British Association, the service from the Cenotaph on Armistice Day, and the re-broadcast of transmissions from American stations all helped to increase the number of listeners.

**Early Difficulties**

The march of progress is seldom unopposed, and broadcasting, as a method of providing cheap and convenient entertainment for the masses, was no exception. Objections were received from all quarters. Mr (later Lord) John Reith, the Managing Director,
divided complaints into three classes: the wholly unintelligible, the altogether ridiculous, and the perfectly reasonable. Among the last were those from commercial undertakings who, rightly or wrongly, regarded broadcasting as unwanted competition. Newspaper owners objected to broadcast news; music-halls and theatres complained of loss of their audiences because people listened in; and amateurs, whose constant demands had led to the service being established, now found it was operating against themselves. These amateurs, already annoyed about having to change their equipment for the move from 1000 m to 440 m, now found they were unable even to use 440 m. They had the alternative of burning the midnight oil after broadcasting hours (always assuming that the BBC was not testing), or of re-modifying their equipment to work on the despised 200 m wavelength.

As Mr Reith pointed out, the BBC made every endeavour to satisfy all reasonable complaints, but their guiding principle was “the greatest good for the greatest number”. Since the greatest number was always the listeners, this was a very safe principle for the BBC to uphold.

The largest source of complaints was the listener himself, who was annoyed by oscillations from the neighbour’s receiver as he “resolved the modulation” from the carrier wave. So many complaints were received that Eckersley published a special pamphlet entitled “Don’t Do It”, which was probably the best-seller of the year. These whistles prompted amateurs to make many suggestions for non-radiating receivers, perhaps the most notable of these being the Lodge N circuit, but none of them attained popularity.

The most vigorous opposition came from the trade union for musicians, actors, and other artists, who saw in broadcasting the disappearance of small concert parties and travelling entertainers. The union tried to keep members from broadcasting by imposing a ban, but the BBC quickly countered this by arranging to furnish its own plays and concerts. It offered to draw up contracts with
any artistes who were willing to ignore the ban, and as there have always been playwrights, actors, musicians, and other artistes who have fallen from the public eye, or have not yet caught it, and are wanting to sell their talents, the BBC had no difficulty in obtaining as many artistes as it could use.

Such troubles were, however, merely passing storms. A constant headache of the BBC was the shortage of money. The initial costs of the transmitters and studios, and the running costs, were heavy but not more so than expected. It was the cost of producing programmes which caused the budget to be exceeded.

The revenue from licence fees was, indeed, supplemented by the royalties on receivers, but these were very small: 1s for a crystal set, 10s for a single valve, 7s 6d for a second, and 5s for each extra valve, and so the sale of a three-valve receiver provided £1 2s 6d. But the majority of listeners used a crystal set and very few used three valves. Also, this was a once only payment. It was hoped that later a continuous revenue would accrue from replacement receivers, but initially, the income was almost wholly from the licence fees.

In this respect it was the BBC who had a genuine complaint, since there were many people who listened to the broadcasts without having a licence. Firstly, there were the amateurs, the whole of whose licence fee was retained by the Government, the company getting no share. Anyone who made his own receiver could call himself an amateur, even if the majority of his listening was to the BBC’s programmes. Then there were firms who manufactured receivers—to listen to amateurs, of course, never to the BBC—which had no BBC stamp and paid no royalties. Finally, there were the thousands of listeners who had constructed their own receivers, or had had one made by a young enthusiast. These people could not buy a BBC licence for the set had no stamp, nor could they claim to be amateurs.

The manufacturer members of the BBC complained bitterly about these home-made sets. It had always been assumed that lack
of skill would discredit the home set maker but, far from this, fine examples of home construction were to be seen and the performance of these sets was often superior to that of the manufactured receiver. It was also claimed that the construction of a receiver gave a satisfaction which outweighed the saving of a few shillings.

To remove the anomaly of the amateur, the Postmaster General withdrew the original amateur’s licence and substituted an “Experimenter’s” licence costing 15s, of which 5s was paid to the BBC. This of course, provided new grounds for complaint by the amateur, who now had to pay extra for the broadcasting service which kept him from listening to amateurs who were not allowed to transmit. By April 1923, the Post Office had issued 115,000 licences of which 80,000 were BBC, and some 33,000 applications for Experimenter’s licences were under examination. But the main

Fig. 3.3 Growth of licences in Great Britain, 1922–24

![Diagram showing growth of licences in Great Britain, 1922–24]
problem still remained: it was estimated that there were at least another 200 000 listeners without licences.

So thorny was this problem that the Postmaster General took legal advice. But this turned out to be most unsatisfactory. Not only was the Experimenter’s licence illegal, but an amateur’s licence could not be withheld from any genuine applicant. Faced with this dilemma the Postmaster General decided to take firm action to avoid further trouble. Despite the questionable legality, he issued an additional “Constructor’s” licence at 15s for non-BBC apparatus, whether home-made or purchased, and fixed a date, 15th October, by which licences were to be taken out if proceedings were to be avoided. During the fortnight before this date 170 000 licences were issued of which only 10 000 were for the BBC. So, by the end of 1923 a total of 585 000 licences had been issued (Fig. 3.3).

Having straightened out the revenue problems, even if only temporarily, the BBC faced trouble on the manufacturing side. The public complained that sealed receivers prevented any modification, also that a low standard of workmanship could be hidden under the seal. The argument that the receiver had passed a Post Office test was rejected, for this applied only to the model approved and not to be production receivers. It should be said, however, that manufacturers had to maintain a high standard of construction in order to equal the performance of home-made sets which incorporated reaction. In fact the handicap was so great that in 1926 manufacturers also started to use reaction and the Post Office ceased to type-test receivers.

By this time the Postmaster General had come to the conclusion that the continuous problem of broadcasting was too much for any one man. Parliament appointed a Select Committee under Major-General Sir F. Sykes to investigate the problem. This Committee was composed of four MPs, the Post Office, the newspapers, the RSGB and the BBC. It acknowledged the national scope of broadcasting and recognized the unforeseen difficulties
which had been encountered. It recommended that the BBC should continue for a definite period, with additional wavelengths to allow it to expand, but a Broadcasting Board should be set up to assist the Postmaster General. On the financial side it was agreed that the cost of broadcasting should not fall on the taxpayers, and neither should the Government profit from the service, but financial dependence on the wireless trade was considered to be undesirable and the Company should be made self-supporting as soon as possible.

The Committee expected most of the revenue to come from licence fees, which it recommended should be 10s for all users, with as much as 7s 6d of that going to the Company. This, together with the royalties on receivers, which should be reduced for valve sets and increased for crystal sets, was considered to be more than sufficient, and a sliding scale was suggested which would reduce the BBC’s share of the licence fee as the number of listeners increased. But to safeguard against over-optimism, the Company was advised to consider other means of increasing its revenue; the Committee even recommended the use of advertisements. Actually the need for additional revenue caused the Company to publish The Radio Times which carried the official programmes. This paper became so popular that by the end of 1925 it was selling over 800 000 copies each week.

Many of these suggestions were embodied in a new licence which extended the BBC’s warrant until the end of 1926. This licence permitted the broadcasting of concerts, theatrical entertainments and other matters, and allowed the names of publishers and the price of books and gramophone records to be given; even commercial advertising could be broadcast if approved by the Postmaster General. It also removed all restrictions on the hours of broadcasting and permitted the company to erect more “relay” stations using wavelengths between 300 and 500 metres.

Each new BBC station increased capital expenditure but this was always offset by a correspondingly large number of new
licences: the prospect of a relay station in Edinburgh resulted in 100 licences per week being issued in the city. Relay stations were quickly installed: Plymouth, Edinburgh, Liverpool, Leeds/Bradford, Hull, Nottingham, Dundee, and Swansea, were opened at monthly intervals.

Fig. 3.4 BBC stations SB network

Fig. 3.5 on facing page: (Top) SB control desk at Savoy Hill (1927) (Bottom) Control table at Savoy Hill. Left to right: input board for selecting programme sources; Marconi B amplifier; output board and amplifier for miscellaneous operations (not part of programme chain). The left-hand meter by the B amplifier is the modulation meter, which shows when the level reaches the point where the transmitter would be overloaded (1925)
Chelmsford (5XX)

By 1924, the BBC had eight main stations and twenty relay stations, representing a capital expenditure of £210 000. The main stations had been expected to have a range of 70 miles, and, indeed amateurs heard them over much greater distances, but, due to the low level of modulation, a good signal for crystal receivers could not be promised at much more than 20 miles during daylight. The relay stations with a power of 120 W had a range of only about 10 miles.

Each main station had its own programme and eight different programmes had to be worked out and correlated; if two programmes included the same musical item at anywhere near the same date there were sure to be complaints. To provide a diversity of programmes the BBC employed twenty-five permanent orchestras with a total salary bill of £100 000. The relay stations took the programme of the nearest main station, or the simultaneously broadcast programme from London, and so did not add greatly to this cost.

These twenty-eight stations still left many parts of the country without a strong signal, resulting in a demand for increased power. The power of the Edinburgh transmitter was doubled to serve the surrounding hilly districts but this gave only a 50 per cent increase of range. The power of the London transmitter was also increased to give a better signal in the Chilterns, but the Admiralty complained of jamming and, to avoid trouble, 2LO was moved to the roof of Selfridge’s Stores in Oxford Street. The transmitter was also rebuilt and all the refinements which had been wired-in during the continuous experimentation were incorporated. Again, the increase of range was less than expected. In the hilly districts, long-wave stations, such as Radio Paris on 1750 m, gave a better signal than the shorter wave stations of the BBC. This led to the idea of an extra station working on the long wavelengths.

The idea of a long-wave station was very acceptable to the
BBC for this would also give better reception in coastal districts where morse from shipping always interfered with broadcasts on the wavelengths near 300 m or 450 m. Such a station, especially if it had enough power, could also be used as a direct link to all the relay stations, giving simultaneous-broadcasting without the cost of Post Office telephone lines, and also a better quality of transmission. The only snag was the doubts expressed of the public’s ability to change the coils in their receivers when changing from short to long wavelengths.

In order to find the public response to this idea, a 15 kW experimental station, working on a wavelength of 1600 m, was constructed at the Marconi works. This transmitter, of similar design to 2LO, used water-cooled valves for the first time in the UK. These valves were operated at an anode current of 1.7 A at 9000 V and put a current of 40 A into an aerial 450 ft high. This was the highest-powered broadcast station in the world and it met an overwhelmingly favourable response from listeners. It was even suggested that two or three such stations could be used to replace all the other BBC’s stations.

But the permanent site for this station raised quite a problem. Political considerations made it imperative that the world’s largest broadcast station should be at the heart of the Empire, but this met with great opposition from Londoners who were already complaining that, at Chelmsford, 5XX interfered with the reception of Radio Paris. Having the station out in the country raised problems of the availability of power, road and rail communications, and water for cooling the valves. The distance from London could not be great, for the distortion with buried cables increased rapidly at distances greater than 50 miles; an open-wire cable route was required near the station.

After much discussion a site was chosen at Daventry, in Warwickshire, on land 600 ft above sea level. The transmitter, which was opened in July 1925, was an improvement on the one at Chelmsford. The oscillator power of 8 kW was amplified to
Fig. 3.6 (Top) 5XX transmitter at Chelmsford. (Bottom) Control room, Newcastle Station (1924)
30 kW by three water-cooled triodes (CAT1), and six CAM1 valves were used in the modulator stage. A T aerial was used, supported on two masts, one 800 ft and the other 500 ft high, and an elaborate earthing system installed.

Broadcasting in other Countries

During this time broadcasting had also been developing rapidly in other countries. In America the pattern had settled down, for while over 1100 stations had been licensed, nearly six hundred had never opened or had closed down. Receiver manufacturers had found that it was unnecessary to own a transmitter to sell receivers; moreover some owners had found the financial costs were too great, and others had closed down due to competition from other transmitters.

In general, the American programmes were poor. The material was provided by the advertisers who paid for time on the air in periods of a quarter of an hour. They were only interested in the advertisements, and so they provided programmes which were just good enough to hold the listener until he heard the “sales-plug”. As the novelty of wireless wore off there was a reaction, and the 5.5 million listeners demanded better programmes. With a large number of stations to choose from they naturally listened to those stations which gave the better programmes, and when no one listened to stations with bad programmes the advertisers took their business to those stations which had more listeners. Because the indirect returns from this advertising were so good, the better stations soon found they had a list of firms waiting for other contracts to end, and they were able to demand higher fees and to insist that the advertisers provided good programmes.

One interesting sidelight on American practice was that artistes, knowing that each programme was a self-advertisement, often paid for the privilege of being allowed to broadcast and get their names before the public.
In Germany, broadcasting had started as a telephone service. The subscribers were of the monied class and the apparatus was installed and maintained by the postal authorities for an annual fee. Normally two boxes were installed, one containing the supplies and the other containing the detector and tuner. There were two types of supply unit, both operating from the mains: the d.c. box contained chokes and condensers to prevent a mains whine as a background to the programme, and the a.c. box contained a full-wave rectifier as well as the smoothing components. Both boxes contained a “barretter” lamp, consisting of an iron wire in an atmosphere of hydrogen, whose resistance increased rapidly with an increase of voltage, so that the current in the filament remained steady. The tuner was set to the transmission wavelength and then sealed to prevent interference. If further amplification was required, a third box containing one or two valve stages was added. The fee charged depended on the number of valves used but good reception was assured from Koenigswusterhausen or one of a number of stations on the shorter wavelengths.

The Australians had also tried receivers sealed to a fixed wavelength but without success. The stations were then divided into two classes, one receiving part of the licence fee and being allowed to accept some advertisements, and the other being permitted to broadcast advertisements all the time. Reception of the second class was free, but reception of stations of the first class was supposed to be limited to those who had paid a fee which varied between £1 and £1 10s for a house, and between £7 10s and £10 for a hotel.

In South Africa, stations were licensed to transmit over a specific area, with advertising limited to 10 per cent of the programme time. The licence fee was 5s, but the listener had also to enter into a contract with the broadcasting station; this cost another £2 per year for a house and £6 for a hotel.

Italy had a number of stations, the chief one being in Rome and operated by the Unione Radio Italiana. A tax of 50 lire was levied, plus an additional tax based on the number of valves.
In France there was no tax but the programmes were so poor that most Frenchmen listened only to foreign stations. The Eiffel Tower, run by the Army, transmitted programmes which were incidental to experiments, and Radio Paris (1750 m), Petit Parisienne (350 m) and École Supérieure (458 m) also broadcast. Each change of government had promised an improved broadcasting service but this had never materialized.

Although Europe was far behind America, by 1925 it had a total of 150 stations in operation and eight of these had power in excess of 10 kW; more were under construction. This increasing number of stations led to a mutual interference at night. Stations operating on adjacent wavelengths often had an audible heterodyne note as a background to both programmes. At first, stations had altered their wavelengths slightly to make the note rise above audibility, a practice which worked quite well; with a little give-and-take each new station managed to settle down between others. But the day came when there was no more slack to take up and new stations remained continuously heterodyning their neighbours.

By 1925, this trouble had become so acute that the sixteen broadcasting companies operating in Europe called a conference at Geneva to sort out the problem. After a long discussion, a three-year interim plan was adopted in which the available wavelengths were allocated to the various countries on a basis of their areas, their population, and the volume of their telephone and telegraph traffic. This allocation of wavelengths was tested for six nights with small changes of wavelength being made to avoid heterodyning. These tests led to the surprising discovery that stations should not be spaced apart by a fixed number of wavelengths: more stations could be accommodated between 300 and 400 m than between 400 and 500 m.

It was known that when a transmitter was modulated by a note of 5 kc/s it radiated two frequencies each 5 kc/s away from the carrier, one on each side, i.e. the transmission occupied a band of
frequencies 10 kc/s wide. It was now realized that to avoid the heterodyne note, stations had to be separated by 10 kc/s. Between 300 m (1000 kc/s) and 500 m (600 kc/s) there was room for only forty stations. On the long waves between 1000 m and 2000 m there was room for only fifteen stations even though there was five times the width of waveband in terms of metres.

The Geneva conference also tried to operate pairs of stations on the same wavelength. These were all low-power stations and were separated by long distances, but even so they interfered with each other at night. The result was that within a year most of these stations were rebuilt with greater power and the problem was worse than before, for now there were new high-power stations elbowing their way into the restricted number of wavelengths. Not only did these stations heterodyne each other, but, because the carrier frequency was not constant, the whistles were continuously changing. To prevent this trouble not only was it essential to start up on the correct wavelength, but the wavelength had to be monitored and adjusted throughout the transmission. Accurate wavemeters were necessary for this and it was soon realized that these were not available.

At this time the wavemeter at most stations consisted of a coil and variable condenser, with a lamp which lit when the condenser was adjusted to resonance. Even when the lamp was replaced by a diode and a microammeter so that an accurate maximum reading could be obtained, the calibration depended on the coil and condenser. These were made especially robust but few wavemeters were better than 1 per cent accurate and about 0.3 per cent was the best obtainable. This meant an error of 3kc/s at 1 Mc/s (300 m). Greater accuracy could be obtained with a heterodyne wavemeter but it is doubtful if more than a dozen of these were in existence in Europe. Not that an accurate wavemeter would have been much help, for the frequency of the oscillator valve in the transmitter changed quickly with changes of supply voltage and, in many stations, even when the aerial swayed in the wind. The tuned
circuit of these transmitters was the anode tuning inductance and the capacity between the aerial and the ground. When this capacity changed so did the station wavelength.

The Marconi Co. in the 2LO transmitter, had overcome this problem by using a separate oscillator valve tuned by a fixed capacity and inductance so that its frequency varied less than 0.05 per cent (500/s at 1 Mc/s). Another valve amplified these oscillations to a higher power before passing them to the aerial. The aerial/earth capacity was now part of the tuned circuit in the anode of the power-amplifier valve and any change of its capacity merely changed the amplification of the stage, and the output power, but did not change the frequency. This master-oscillator/power-amplifier circuit was found to have an additional advantage in that the amplifier valve could be biased so that the same power was produced with less anode current, or the power output could be increased with the same d.c. power from the supply. In practice, the bias could be set to beyond the cut-off value and changing the bias gave an easy method of varying the power of the transmitter.

The master-oscillator/power-amplifier circuit was also used in the long-wave 5XX station, which had a remarkably steady carrier frequency, and this type of circuit was rapidly introduced into other broadcasting stations as the necessity for a constant frequency was recognized.
CHAPTER 4

Home Constructors

Home Construction

Perhaps it was a good thing that the first years of broadcasting were dominated by the home-constructed receiver. Not only were these cheaper than the factory-built models, they were usually more sensitive and selective and, more important, they could be modified to keep abreast with every new development as it was published. During this time every circuit which had ever been published, and many new ones, were tried again and the best of these, super-regenerative, reflex, and supersonic-heterodyne, were made by home-constructors long before they were mass-produced.

The popularity of home construction caused a number of wireless periodicals to appear. Wireless World, Amateur Wireless, Popular Wireless, Modern Wireless, The Wireless Constructor, Wireless, and Experimental Wireless, were published weekly or monthly, and each had a circulation of between 100,000 and 250,000 copies. Most of these gave a free blueprint with each issue, showing the component layout for an “entirely new” receiver. A new component, which was stated to be a vast improvement on others, a slight change of circuit or even an existing circuit redrawn, each
was sufficient to qualify as a new circuit. Actually, few constructors ever copied a published circuit, for they all possessed some components and used those instead of buying the new ones described. They modified both design and layout, for after all they were experimenters. In practice they found little difference in performance; very few of the new components lived up to the manufacturers' claims.

The BBC's policy of providing a signal for the crystal set prompted most listeners to start with this type of receiver. An amazing number of crystal sets were made; cheapness was one attraction, for few people expected "the wireless" to be more than a passing craze for the boy. The ease with which these sets were made caused the price of the manufactured set to drop from £2 in 1922 to 6s in 1925; for £2 10s one could obtain the set, the aerial wire, and a pair of headphones.

Probably the crystal set would never have attained this popularity had it not been for the production of synthetic crystals. As early as 1913, Fry showed that the sensitivity of natural galena increased after it had been heated; this fact was probably forgotten during the war, but in 1924 Hertzite crystals, produced by heating lead and sulphur in a muffle furnace, were found to have a large number of sensitive spots, and soon these, and the permanent Perikon detector, were the only ones used.

Fig. 4.1 Early crystal set made by the National Wireless Co.
Fig. 4.2  Early Marconi receiver Type V2A

Fig. 4.3  Home made three valve set
Scientists never decided how the crystal detected. The various theories ranged through all the electric effects, but always there was something which ruined the theory. Electrostatic action by changes of a film of dielectric at the contact point was rejected because any trace of oil or grease ruined the action. Electrolytic action by an oxide of the cat's whisker was discounted, for many crystals only detected when biased while others needed no bias. Heat theories embraced both the thermal (Joule) effect and the
thermo-electric (Seebeck, Peltier and Thompson) effect. Eccles showed that a temperature rise existed at the crystal contact, but this did not explain why amorphous galena was useless while even microscopic crystals made good detectors. Many crystals operated at some critical temperature, but crystals having good piezo- or pyro-electric effects were poor detectors. A temporary application of heat could also cause a poor crystal to become, and stay, sensitive. Strachan examined the structure of crystals but learned little from this. The only sure facts were that sensitivity depended on the chemical composition and the purity of the crystal and on the pressure and cleanliness of the contact. The only advice taken by the listeners was to keep the crystal clean, to use forceps to handle it, and to use a cover such as a glass tube to keep out the dust.

Listeners soon tired of the crystal receiver. There was the annoyance of having to find a sensitive spot each time vibration jarred the cat’s whisker. The output was small and allowed only two pairs of headphones to be used. Wearing headphones was fatiguing, a high degree of concentration in listening being necessary for even the rustling of a newspaper could drown the sounds. The earphones were often dropped into a glass bowl so that the whole family could listen to a particularly good programme, the bowl acting as a resonator. From this the next step was, of course, to use a loudspeaker, but this required a valve amplifier.

Loudspeakers

It was the son of the house who first sold the idea of the wireless to the family, usually buying the parts for the crystal set from his own pocket-money. It was he, also, who persuaded the family that a loudspeaker was necessary. He probably had a variety of reasons, from the competition for the headphones, to the conflicting desires of listening and doing something else, and the desire for further experiments. But even before he had persuaded the family to invest
in a loudspeaker receiver—his pocket-money was not sufficient to cover the cost—he had clearly formulated the circuit to be used, the components he was going to buy, and the way these were to be laid out inside the cabinet. He usually decided to make a two-valve receiver, for the single-valve receiver, even with reaction, was not adequate to drive a loudspeaker.

Loudspeaking instruments were not new, the earliest forms having been made for the first telephone. In 1872 Edison invented a loudspeaking receiver consisting of a diaphragm carrying a point contact which rested on a chalk cylinder; the cylinder was rotated and so dragged the contact, pulling the diaphragm from its normal position (Fig. 4.5(a)). The cylinder was wet with potassium iodide and the passage of a current through the contact varied the friction to produce a movement of the diaphragm which resulted in loud sounds. In 1879, Elisha Grey mounted a Bell receiver at the centre of an iron pan, and the telephone currents caused the pan to vibrate (Fig. 4.5(b)). Another early design, by Lodge, used a coil mounted in an annular field and connected to give a push-pull motion. The coil was attached to a sounding board, and formed the first moving-coil loudspeaker (Fig. 4.5(c)).

From 1900 to the days of broadcasting, all the developments in loudspeakers were for application to the gramophone. There, the needle movements vibrated a mica diaphragm in the sound box to cause air movements in the tone-arm which was, in turn, attached to a metal horn acting as a megaphone to pass air movements into the room. In 1907 Starling and Cole described the Vitaphone reproducer (Fig. 4.5(d)) which used a cardboard cylinder to carry the stylus, and had a paper cone, eight inches in diameter, attached to the cylinder; when the stylus vibrated, the paper cone set the air in motion. Lumière also patented a loudspeaker with a paper

Fig. 4.5 on facing page: (a) Edison chalk cylinder loudspeaker; (b) Elisha Grey pan loudspeaker; (c) Lodge moving-coil loudspeaker showing pot magnet and coil; (d) Vitaphone loudspeaker; (e) Sterling Primax (Lumière) loudspeaker and method of manufacture

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diaphragm but this was made rigid by crimping it together along one edge and flattening out the other to provide a circle which was thick at the centre and tapered to the edge (Fig. 4.5(e)). This construction gave a decidedly better tone to the sound, particularly in the lower notes, but the level of the sound was low and so it was not popular.

In 1910 S. G. Brown used a small conical diaphragm in a telephone earpiece. He used a reed armature instead of the circular diaphragm and attached the reed to a cone by a lever system; a flat ring of flexible material bridged the gap between the cone and the case of the earpiece but left the outer edge of the cone free to vibrate.

The next important step was by Hopkinson, who used a 9 in diameter cone rigidly fixed at the rim by a pair of heavy rings which also supported the operating mechanism. A system of levers connected this cone to the stylus. This reproducer also gave a better tone with a lower volume so it too was largely ignored.

For his radiotelephony experiments Fessenden modified Edison’s loudspeaker, using a metal cylinder dipping into oil, and a metal band replacing the single contact. The band was held away from the cylinder by a thin film of oil. This reproducer was further developed by Johnson and Rahbeck, who used an electric motor to rotate a cylinder of semiconducting material. The metal band was retained by a spring at one end and a polarizing potential between the band and the cylinder caused the diaphragm to be pulled in the direction of rotation to give loud signals.

Another very loud reproducer was the Stentorphone invented by Gaydon, which used compressed air to give pulsating blasts. The stylus caused a slotted metal plate to vibrate and allow the air to pass through the slots. The sound quality from this loudspeaker was comparable with that from the normal horn type but was very much louder.

The early wireless loudspeaker grew from putting the gramophone horn on top of the earpiece, but loud signals cause a rattle as the diaphragm hit against the magnet poles. Larger earpieces,
called horn units, were introduced and these had adjustable magnets which could be moved nearer to the diaphragm when the signals were weak. These units were fitted to horns of all shapes and sizes, from a simple megaphone to horns 3 ft long with flares opening up to 18 or more inches in diameter. These horns were bent into various artistic shapes, but it is doubtful if the designers even realized that there were acoustic principles to be considered.

Some listeners complained that certain notes, particularly the ones obtained by tapping the metal horn, tended to ring, or persist longer than the others. They demanded a better quality of sound and advocated the use of horns made of ebonite or papier mâché which did not ring in this manner. As such horns gave an equal loudness, and could be made cheaply, they soon became popular and within a few years the metal horn had almost disappeared.

Larger horn units were also produced in an effort to give better low notes but while there was little improvement of the bass, these units did permit larger magnets to be used, which gave a greater sensitivity and a larger sound output.

**Super-regeneration**

While a few older listeners were content to listen to the local station, it is probably true that more than half of the listeners spent most of their time tuning from one broadcasting station to another and making lists of the stations they heard. They only listened to a programme until the station call sign was given and then searched for another station. These men needed a very sensitive and selective receiver in order to boast of a larger number of stations than the man next door, and they also developed the art of adjusting the reaction, or regeneration, control to a fine degree.

It had been realized quite early that even when the reaction control was set as fine as possible, the audible howl when the receiver oscillated was considerably louder. Attempts had been made to obtain this extra loudness. If the valve was biased until
the anode current was just not sufficient to maintain an oscillation, a signal would raise the current and cause the howl. Unfortunately, once triggered, there was a steady oscillation which continued even after the signal stopped and until the receiver was switched off.

In 1916 Turner designed a circuit in which a relay operated whenever the valve oscillated. The contacts of this relay short-circuited the reaction coil and stopped the howl. Then, if the signal was still present the circuit immediately started to oscillate again, but if the signal had ceased, the circuit remained quiet until the next signal was received. By using a relay which operated faster than the incoming signals were keyed, the valve could start and stop oscillating some five or ten times for a dot and three times for a dash. In this way, Turner turned a c.w. signal into an i.c.w. signal without a heterodyne note. At each burst of oscillation the valve operated at its maximum power, giving an output greater than that of a heterodyne receiver.

A similar circuit was described in 1919 by Bolitho, who used a valve with reversed feed-back to quench the oscillations. The grids of the two valves, detector and quench, were connected together, so that the anode current of both valves varied at the frequency of the incoming signals (Fig. 4.6a), but the second (quench) valve was supplied from an alternator and its anode current flowed only on alternate half-cycles to give reversed reaction and stop the oscillations.

In 1922 Armstrong in the USA took this type of circuit a step further using a valve oscillator to quench the signal oscillations. This quench oscillator could be adjusted to give any rate of stopping and starting, from an audible signal for morse to a supersonic one for the reception of i.c.w. or r/t signals. With the supersonic quench frequency an extra valve was sometimes necessary to give audible signals. Armstrong described three circuits (Fig. 4.6c). In the first, the quench voltage lowered the detector anode voltage to a point where it no longer maintained oscillations; the second
applied reversed feedback to the oscillator coil, similar to the Bolitho method, and the third was a combination of these two methods. A single valve was made to operate as both oscillator and quench valve, with two feedback circuits, one at signal frequency and the other at quench frequency, so that the anode potential varied at both these frequencies.

The disadvantage of the super-regenerative circuit was that a frame aerial was necessary to prevent the oscillations being radiated. A frame aerial reduced the strength of the signals but, as these were amplified to the maximum output of the valve no loss of signal strength was apparent. Another disadvantage was that the largest power was obtained with the lowest quench frequency, or when the oscillations were least chopped (largest on/off ratio). But if the quench frequency was adjusted to be just above audibility, an unheard hiss was always present and the operator usually woke up next morning with a severe headache. A filter, consisting of a coil and condenser, could be used in the telephone circuit to remove this inaudible whistle.

In setting up this receiver, a weak signal was first tuned with the quench coils set apart, and then the coils were drawn together until the quench oscillations were obtained, after which the reaction coils were brought together to obtain the extra amplification. Subsequently both the quench and reaction coils were adjusted at the same time to obtain the best signals. In operation, once the quench oscillations were set up it was rarely necessary to adjust them again and the receiver was very easy to tune; in fact it was more stable than a critical reaction circuit. The one fault was an apparent lack of selectivity, for even when off-tune the weak signal still gave full output.

Another super-regenerative circuit, by Flewelling in 1922, produced the quench oscillations by charging and discharging a condenser in the grid circuit (Fig. 4.6b). The control was made variable and could be adjusted more easily than the swinging coils of the Armstrong circuit. These circuits were in vogue for about a
Fig. 4.6 Super-regenerative circuits: (a) Bolitho's circuit; (b) Flewelling circuit; (c), on facing page, Armstrong's three circuits
year, after which the annoyance to the neighbours by radiation caused them to fall into disfavour.

**Reflex Circuits**

The high cost of valves, and the royalties on each valve stage, created a desire to obtain the maximum performance from each stage, and attention was turned to the reflex receiver where one valve was used to amplify the signals at both r.f. and a.f. During the First World War Latour had used reflex valves in cascade, the incoming signal being passed through the valves which amplified it at r.f.; it was then detected and returned to the first valve to pass through them again, providing amplification at a.f. (Fig. 4.7a). The objection to this circuit was that the first valve received both the weakest r.f. and the weakest a.f. signal, while the last valve was required to handle the strongest signals and could be overloaded. Grimes overcame this difficulty by an inverse-reflex circuit (Fig. 4.7b) in which the signals passed through in the normal manner at r.f., but a.f. signals were first applied to the last valve and thereby worked back to the first, the first valve having the weakest r.f. and the strongest a.f. signal.

Few manufacturers used the reflex circuit, for it had all the troubles of the r.f. amplifier: the wiring of the receiver had to be moved during the final test to prevent oscillation, and wires could always move again during transit to the shop or the customer. Trouble usually centred around the transformer. When this was connected in series with the tuned circuit the by-pass condenser was critical; too large a capacity caused distortion, and too small a capacity gave instability or oscillations. When the transformer was in parallel with the tuned circuit an r.f. choke was required in series to prevent the signal being by-passed and a small condenser was put in series with the tuned circuit to stop the a.f. signal being short-circuited (Fig. 4.7c).

In 1924 Scott-Taggart published the ST100 circuit (Fig. 4.7d),
which was built by a large number of home constructors. This receiver had one reflex valve and a crystal detector but produced results which surpassed anything obtained before. Thirty or forty stations on the loudspeaker was not unusual; in fact the circuit was so successful that it was in vogue for about three years.

The Superheterodyne Receiver

One other special receiver which must be mentioned was the superheterodyne receiver. Although very sensitive and selective, it was used by only a very few people owing to its large number of valves. The superheterodyne receiver was devised at the end of the First World War, more or less at the same time, by three people who arrived at the same point from different beginnings.

The first was Levy (France), who wished to remove jamming from signals on wavelengths between 100 and 600 m. Knowing that tuned circuits were more selective on long waves, Levy had the idea of heterodyning the incoming signals, not to give an audible note, but to give a beat note at an ultrasonic frequency (30 kc/s) which could be selectively tuned by a long-wave receiver. A signal on 200 m (1500 kc/s) was heterodyned by an oscillator set to 1470 kc/s to provide a beat-frequency of 30 kc/s, which was passed to a long-wave set tuned to 10 000 m. Another signal on 195 m (1538 kc/s), which normally gave severe jamming, would also be heterodyned and give a beat note of 68 kc/s (4400 m). This was easily separated from the 30 kc/s signal by the long-wave tuner (Fig. 4.8a).

The second approach was in Germany by Schottky, who had difficulty in receiving weak signals on short waves due to the instability in his r.f. amplifiers. Schottky decided that if the incoming signals could be converted by a heterodyne into a lower frequency they could then be amplified quite easily (Fig. 4.8b).

The third approach, and the one which obtained the most
Fig. 4.7 Reflex circuits: (a) cascaded reflex circuit; (b) inverse reflex circuit (dotted lines show a.f. path); (c) Round's parallel circuit; (d) Scott-Tagger ST-100 circuit.
Fig. 4.8 Superheterodyne circuits: (a) Levy’s circuit, 14th August, 1917; (b) Schottky’s circuit, 18th June, 1918; (c) Armstrong’s circuit, 30th December, 1918; (d, on facing page) Superheterodyne receiver used by the Glasgow and District Radio Club in the transatlantic test (1920)
publicity, was by Armstrong of the USA. The American Expeditionary Force came to Europe equipped with long-wave transmitters and receivers and found the Allies were working almost exclusively on short waves. As it was not practical to modify this equipment, Armstrong suggested the use of an add-on unit which would produce supersonic beats and these could be passed to the long-wave receivers. This unit carried two valves, one to detect and the other to provide the heterodyne frequency. The anode circuit of the detector valve had a circuit tuned to 100 kc/s (3000 m) which was coupled to the aerial and earth terminals of the long-wave receiver. An additional advantage claimed for this receiver was that the only tuning controls were the signal and heterodyne oscillator circuits; the six or more circuits of the long-wave tuner, having once been adjusted to the supersonic frequency, needed no more adjustment. In practice, only the oscillator tuner needed careful adjustment for the signal circuit was very unselective.

A superheterodyne receiver was used by the Glasgow and District Radio Club in the first transatlantic tests (Fig. 4.8d). It was a club effort with various members lending parts of the apparatus which had two valves for the first detector and heterodyne oscillator, a three-valve long-wave amplifier unit with capacity reaction, a second detector, and a three-valve a.f. amplifier unit. But, as with most other listeners, no American stations were identified.

Attempts to popularize the superheterodyne receiver met with almost no response in Britain. The main objection was, of course, the number of valves; besides their initial cost the amateur had to consider the filament current they required and his charging problem. The radiation from the heterodyne oscillator, which made a frame aerial necessary, was another objection. The reduced signal pick-up cancelled out the extra amplification, and the frame needed to be rotated while searching for a distant station; a weak signal could be passed over because the aerial was pointing in the wrong direction. Perhaps the real reason for its unpopularity was merely because it was unnecessary. Signals from the BBC’s stations were
so good that the normal listener needed neither the extra sensitivity nor the selectivity of the superheterodyne receiver.

**Mass-produced Valves**

Before 1923 valves were hand-made. This had the advantage that it allowed many special valves to be made for amateur and professional experimenters. Some types were made with two filaments, the second to be used when the first was burnt out; others had two grids, or two anodes (or both) and valves with different shapes or spacing of electrodes. Donnithorpe had a valve with a coil of wire outside the bulb to create a magnetic field which controlled the emission. Majorama patented a tetrode valve with two interlaced grids to give full-wave detection, but, as the grids had only half the number of turns, giving only half the control, the signals were no louder. This valve was, however, used by the Marconi Co. to avoid the grid-leak patent.

Another Marconi valve used two concentric grids, the inner one being made positive to reduce the space charge and the outer one connected to the tuner, but the increased distance to the outer grid lowered the control by about the same amount that the inner one increased the anode current. Schottky patented a similar
valve with the outer grid made positive. This maintained the control but the voltage to the outer grid had to be half the h.t. voltage and a large signal often caused the valve to oscillate uncontrollably.

Such four-electrode valves were, however, used in reflex circuits with the r.f. applied to one grid and the a.f. to the other. In France, these bi-grille valves were extensively used in superheterodyne receivers for the dual function of first detector and oscillator. The signals were applied to the outer grid and the oscillation took place between the anode and the inner grid. Both signals varied the emission and the beat frequency was separated by a tuned circuit in the anode.

Another four-electrode valve, introduced by Scott-Taggart, was called the “Negatron”. This had two anodes mounted as a diode and triode on opposite sides of the filament. The emission divided between these two and when the grid became positive the triode current increased and the diode current decreased. The diode was connected across the tuned circuit and its anode current normally damped the circuit. A signal decreased the diode current and apparently the circuit resistance was negative.

The advent of broadcasting required a large number of valves and manufacturers started to mass-produce them. Within a short time the price of valves fell and this added impetus to the change from the crystal set to the valve receiver.

The mass-production of valves required great care at all stages. The materials had to be carefully selected and all machining and assembly had to be to close limits; a hard vacuum was also essential. The glass had to be of suitable diameter, with uniform wall thickness, a high softening temperature and good heat conduction. The metals had to be pure. Nickel anodes were stamped from a flat strip and bent automatically into a circle and grids were wound as a continuous spiral and spot welded at the correct spacing to nichrome or molybdenum supports before they were cut to length. Platinum wires were then welded to these supports to
Fig. 4.10 Types of mass-produced receiving valves and processes in their construction:
(a) glass flange; (b) construction of leading-in wires; (c) complete assembly of foot with wires fused into "pinch" and exhaust stem attached; (d) cylindrical anode; (e) "flat" or oblate anode; (f) cylindrical grid with a single support wire; (g) "flat" grid with "hairpin" support; (h) electrode assembly in bright emitter valve, showing spring tension on filament; (j) "06 filament and support prior to assembly; (k) electrode assembly of "06 valve; (l) low-temperature filament supported without spring tension; (m) method of springing straight horizontal filament; (n) springing of inverted V filament; (p) original shape of bulb; (q) valve ready for exhausting; (r) "gettered" valve ready for cementing to standard 4-pin cap, (s)
provide vacuum-tight supports into the glass. After fabrication and before they were assembled into the valve, all these metals were heated in a hydrogen atmosphere to remove any impurities.

Special rotary frames which carried a number of gas jets were designed. One machine made the glass pinch: the lead-out wires were assembled in the correct positions in a glass tube which was heated and squeezed to secure the wires in position. This pinch was passed to another frame where the electrodes were welded to the lead-out wires before passing to a third frame where the glass bulb and the foot was attached. From there the valves passed for pumping: first, a test was made to ensure there were no leaks, and then it was evacuated by a reciprocating pump, backed-off by a rotary pump to give a vacuum of 1 mm of mercury, and again by a diffusion pump to give 0.001 mm. Another stage applied voltages for running on the pumps. With the filament heated, an oven was brought down over the valve until the correct temperature was reached. The valve was then made to pass current until no blue glow appeared even with the full h.t. applied, after which it was sealed and a getter was fired to produce a vacuum of 0.000 000 1 mm of mercury.

Although mass-production gave cheaper valves, it was the introduction of dull-emitter valves which revolutionized the industry. These required only a tenth of the filament power of the R-type bright-emitter valve, and made visits to the charging stations less frequent.

Two types of dull-emitter were developed more or less simultaneously—the oxide-coated filament, and the thoriated-tungsten filament. Early oxide-coated filaments always lost their emission after a short time, but by applying alternate layers of strontium hydroxide and barium resinate, with gold and silver to hold the layers together, this trouble had been overcome. The thoriated-tungsten filament was originated by Langmuir, who showed that filaments containing thorium had an emission 100,000 times that of tungsten; the heat caused thorium to seep to the
surface of the metal and it required less energy to release electrons. The emission of an R-type valve was achieved at a dull red heat (1250 to 1650°C) and a thinner filament could be used. Instead of 3 W (0.7 A at 4 V) less than 0.5 W (0.2 A at 1.8 V) was required.

Both these dull-emitter valves required a very hard vacuum, for any residual gas soured the surface of the filament and changed the oxides, or the thorium, into chemical compounds of poor emitting quality. This raised a production problem, for the filaments could not be run on the pumps. The trouble was overcome by using a radio transmitter to induce eddy currents into the metal electrodes to make them red hot without applying any voltage. This was probably the first use of radio heating.

Dull-emitter valves made by the B.T.H. Co. and sold for £1.7s each required only 0.06 A at 3 V and could be operated from a dry battery. In spite of the thinness of these filaments they were very robust but tended to vibrate if the valve was tapped, the filament moving in relation to the grid and so changing the anode current flowing. Such a vibration could be caused by sound from the loudspeaker hitting the receiver cabinet and being passed to the valvholder; certain notes tended to ring and could even set up a howl in the loudspeaker. This microphony was overcome by raising all valvholders onto rubber pads to isolate them from the vibration. Later, manufacturers produced valvholders with springs on the pins. These springs had to be strong enough to withstand the strain of inserting and removing valves but weak enough to damp out any vibration.

**Distortion**

By 1924, collecting lists of station names was losing its appeal. The general public had begun to accept the broadcast programme as a new social amenity, similar to the gramophone but without the trouble of changing records. The opening of the high-power station caused them to realize that broadcasting had come to stay and many
constructors gave up listening to distant stations and concentrated on improving the quality of their receivers. Considering the strange sounds which came from the horns of both gramophone and wireless loudspeakers it is not surprising that enthusiasts did not like comparisons between them, or that they tried to improve them.

McLachland showed that although most of the speech energy was in frequencies between 300 c/s and 1000 c/s, the intelligibility of the speech depended on the reproduction of consonants (particularly t, p and s), all of which included much higher frequencies than were transmitted. Any removal of high frequencies from the transmission, or reception, caused the speech to be muffled. He also showed that the piano was a most difficult instrument to transmit, for its percussion action caused the majority of the power to be in the fraction of a second after the hammer had struck the string. This energy could be ten times the average energy and could over-modulate the transmitter.

Thomas pointed out that some distortion occurred at every stage of the system, from the microphone at the transmitter to the loudspeaker in the home (Fig. 4.11). Equal changes of pressure at a carbon microphone caused unequal changes of resistance, the curvature of each valve characteristic gave unequal changes of anode current, and many other components, especially chokes and transformers, added to the distortion, which accumulated all the way to the transmitter aerial. For some unknown reason the path between the transmitter and receiver was assumed to be distortionless, except for atmospherics and these were beyond the control of either the BBC or the home constructor.

At the receiver, a tuned r.f. amplifier, even assuming it was not on the verge of oscillation, gave distortion in each tuned circuit and in each valve. The station radiated frequencies on each side of the carrier, but the tuned circuits gave a higher voltage from the carrier than from the sidebands. The greater the selectivity, the less the volume from the higher notes. This effect had been
noticed when using reaction, the pitch of the sound becoming lower as the reaction, and the selectivity, were increased. The output from the detector increased as the square of the signal, making loud sounds louder, and this signal was further distorted by the a.f. stages before it passed for a final blurring in the loudspeaker. In fact, everything considered, it was surprising that the sound from the loudspeaker bore any resemblance to the original sounds.

The BBC was well aware of this distortion and made every endeavour to improve its transmissions. Indeed, at this time the distortion at the transmitter was considerably lower than that in any but a few receivers, and the BBC always encouraged the listeners to improve their receivers.

Fig. 4.11 Distortion: (a) microphone; (b) valve
With the gramophone there were three ways of changing the tone. One could change the sound box, the tone-arm, or the horn. Similarly, with the radio receiver it was shown that a loudspeaker giving good results with one receiver gave a distinctly inferior performance with another, or the loudspeaker had to be chosen to suit the receiver. Nevertheless, the obvious place to start to improve the reproduction was at the loudspeaker, and various shapes and sizes of horn were tried, but all of these were rejected as being unsatisfactory to the musical ear.

The loudspeaker unit was investigated. Sandeman showed that about 2 mW of electrical power was required for the loudspeaker to provide an audible sound equal to that of speech (125 ergs or 0.0125 mW), thus the efficiency of the normal horn unit was only 1 per cent. This figure was confirmed by Balbi, who measured the efficiency by connecting two units back-to-back. During the tests it was noticed that the impedance of the unit varied with frequency but, as the loudspeaker units measured were considered to give good reproduction, these figures were regarded as unimportant.

Mallet sprinkled sand on the unit diaphragm. This collected at the parts where there was no vibration and, at the frequencies which gave the loudest sounds, lines or circles were produced by the sand. Similar resonances were also shown with the telephone earpiece but these were not usually noticed because the diaphragm was pressed close to the ear. The use of a horn also acted to reduce the resonances of the unit, for the column of air gave a back pressure which restricted the movement of the diaphragm and damped the resonances. Nyman showed that a rapid change of pressure at the mouth of the horn could cause air waves to be reflected back down the horn, setting up standing waves, as in a bugle. He stated that the length of the horn and the size of its mouth should be at least a quarter of a wavelength of the lowest note required.

Hanna and Slepian drew an analogy between the radiation from the loudspeaker and that from a transmitter aerial. The unit was considered as an oscillatory circuit which dissipated its energy by
moving the diaphragm against the resistance of the air column in the horn. In a narrow tube the air moved faster and the back pressure was greater, so that the diaphragm had to work against a higher resistance to do the same amount of work.

A diaphragm of $2\frac{1}{2}$-in diameter, which moved 0.1 in, moved 1.96 in$^3$ of air, and all this air had to pass through the throat of

![Diagram of exponential horn](image)

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*Fig. 4.12 Exponential horn*

...the horn. But the maximum speed of this air was 1100 ft/s, the velocity of sound in air; so a throat of $\frac{3}{4}$-in diameter could move 5800 in$^3$/s and the highest possible frequency was 3000 c/s. To reproduce a higher frequency, either the throat area had to be made larger, with less damping on the unit, or the diaphragm had to move less air, giving a lower volume. This energy had to be radiated and the pressure reduced to the normal atmospheric pressure at the
far end. Reflections were prevented by opening out the tube so as to give a steady decrease of pressure, and experiments showed that a logarithmic, or exponential expansion, was best. By this means the diameter of the horn doubled itself for equal distances down the tube. A throat of \( \frac{3}{4} \) in diameter had to double itself six times to obtain a diameter of 48 in which was a quarter wavelength for a note of 70 c/s, and if the horn was to be a quarter wavelength long it could not double itself in less than a distance of 8 in. Experiments showed that the horn should double itself at each 12 in for a note of 64 c/s, giving a horn length of about 6 ft.

Such a horn was obviously too long for the drawing room and it was often bent to take up less room, but bending produced a number of paths for the sound and changes of the wavefront caused blurring. A number of concentric tubes were tried within the horn to divide it throughout its length, but this presented mechanical difficulties. An easier method was to divide the horn into two or three parts which were reversed within each other. This re-entrant construction divided both the length and the cross-section of the horn.

One of the first re-entrant loudspeakers was made by Amplion, who divided the horn into two parts, the smaller being reversed
into the flare of the larger so that the sound was thrown back into the mouth. A.T. & T. Co. used a horn divided into three parts so that the horn unit was at the rear (Fig. 4.13), and His Master's Voice used four parts for their re-entrant tone-chamber gramophone. In this the first section supported the third section, which, in turn supported sections two and four. These sections all nested together to form a cubic box of about a 2 ft side.

The ungainly size of the exponential horn caused a revival of the large conical diaphragm loudspeaker. Resonances in the diaphragm of the horn-unit were avoided by its being driven by reed units similar to those in Brown's earpiece. Farrand in 1921 used a cone held rigidly around its periphery and had the driving unit within the cone (Fig. 4.14). The Western Electric Kone loudspeaker (1921) had the edge of the cone bent over to make it more rigid, and this left the whole cone free to vibrate (Fig. 4.15). In 1923 Huguet d'Amour used two cones cemented together at their rims and supported by two rings which clamped one of the cones but allowed

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Fig. 4.14 Farrand's cone loudspeaker with moving coil drive
the rest of the assembly to vibrate (Fig. 4.16). Western Electric made a similar cone and mounted the driving unit on the clamping rings.

The improved quality with all these loudspeakers was always at the expense of volume, a sacrifice the public was not prepared to make. The first hornless loudspeaker to become popular on the
British market was the Sterling Primax, costing £6, which had a pleated diaphragm after the Lumière pattern (see Fig. 4.5e).

In 1924 Hopkinson showed that the low volume found with these large cones was due to the air waves not moving out into the room. The pressure due to the cone moving forwards passed around its edges to cancel the rarefaction produced at its back. He glued the edge of the cone around a hole in a large sheet of balsa wood, at least a quarter-wavelength long for the lowest note, which baffled the air movement around the edge. This baffle-board greatly improved the reproduction of low notes.

Also in 1924 Rice and Kellogg of the American General Electric Co. patented the Magnivox loudspeaker. This was a development of the Lodge type of loudspeaker in which the diaphragm moved as a piston. A paper cone, of about 6 in diameter, was supported at its edge by a rubber ring to give an almost free suspension. This rubber ring was glued to a baffle-board and its natural frequency of movement was well below audibility. The cone was driven by a coil which moved in a radial field from an electromagnet, which required an extra battery. The efficiency of this loudspeaker was even lower than that of the reed but large powers could be applied to the coil, which, in turn, could move over a large distance, pushing a large amount of air. With large valves this moving-coil loudspeaker gave enough sound to fill a hall with very high-quality sound.

**Improved Audio Amplifiers**

Attention was turned to removing distortion from amplifiers. Early amplifiers using transformer-coupled R-type bright-emitter valves had provided a gain of 20 for a stage, but any attempts to obtain an overall gain of more than 200 from two or more stages had always ended in continuous oscillation. By 1924, through keeping the input and output leads well apart and carefully positioning the transformers so that their iron cores were at right-
angles to each other, it was possible to obtain an overall amplification of about 1000. But the greater the amplification the greater was the inequality at various frequencies due to resonances in the transformers.

At this time, transformers were still made by rule-of-thumb, even though in 1913 Kolster had shown that the action of an inter-valve transformer was very different from that of a transformer for the supply mains. Usually, half the winding space was given to the primary and the other half to the secondary. The secondary was wound with the thinnest gauge of wire the machine would handle and then, knowing the required step-up ratio, the number of primary turns and the gauge of this wire could be calculated. The gauge of the primary wire, in turn, set a limit to the anode current of the preceding valve.

All transformer windings were dipped in wax which both kept the wires in place and also excluded moisture, but this wax increased the self-capacity of the winding, which Kolster had shown would resonate with the inductance of the winding to cause the transformer to act as a tuned circuit somewhere in the audible frequency range.

Some manufacturers tried to keep this capacity small by inter-leaving dry paper between the layers of winding; this made machine-winding easier but fewer turns could be wound in the same space. Others tried sectionalized windings, but the number of coils which had to be joined together made such transformers impossible to mass-produce. The Western Electric Co. made the width of the winding small compared with its depth, which made a simple, cheap, product with a lower capacity but which was awkward to mount in a receiver.

The RCC stage also had its problems. Not only was the gain lower, requiring more stages, but the h.t. had to be high if the full anode current was to be passed. The coupling capacitor also had to be of mica dielectric for no leakage could be tolerated. Anode resistances made of graphite gave "fizzy" noises which
marred the reproduction, but wire-wound resistors to reduce this noise were expensive, making the cost of a resistance/capacity-coupled stage as high as that of a good transformer.

Barkhausen in 1919 had tried to analyse the transformer-coupled amplifier, including the valve capacities. This was taken a step further by Miller, who showed that the grid-anode capacity also had a large effect in the action. In an RC amplifier this capacity apparently caused an additional resistance and capacity in the grid circuit, but when an inductance was in the anode circuit the effect of this capacity was similar to that of removing resistance from the grid circuit. This partly accounted for the tendency for two transformer-coupled stages to oscillate.

McLachland showed the inductance of the primary winding changed with the amount of anode current flowing in the coil; also, the effects of hysteresis and eddy currents in the transformer increased with the frequency of the signal. The capacity between the primary and secondary windings added complications, for some of the energy passed through this capacity at high frequencies. To reduce this effect the start of the primary winding was connected to the anode and the finish of the secondary winding connected to the grid of the next valve, leaving the other two adjacent connections to go to the h.t. and grid-bias batteries, both of which were “earthy” and tended to screen the two windings from each other.

Graham and Rickets showed that improved amplification could be obtained at low audio frequencies by using an iron-cored choke to couple the stages, instead of a resistance. This rendered the large h.t. of the RCC stage unnecessary. But the amplification with this stage was no better than the RCC stage for it lacked the step-up of the transformer, also, the reproduction of low notes was not as good as the resistance/capacity-coupled stage.

Pearson regarded the transformer as a choke-coupled stage in which the voltage produced across the primary inductance was multiplied by the step-up ratio. He then referred all the secondary
capacities, including the self-capacity and the valve grid-filament capacity, to the primary side of the transformer, and so calculated the resonant frequency of the coupling.

Attempts to verify all these theories were not easy, however. The measurement of small voltages at audio frequencies was not possible at this time and any leads connected to an amplifier added to the stray capacities and could even cause oscillation. Smith and Napier compared the input and output signals by using a special variable transformer, made like a radiogoniometer. The rotor coil was connected to an audio frequency oscillator, and one pair of the fixed coils was connected to the input of the amplifier. The other pair of fixed coils was connected by a switch to an earpiece; in the second position, the switch connected the earpiece to the output of the amplifier. The rotor was turned and the switch reversed until the sound in both switch positions was equal. Then the gain of the amplifier was established from the angle of the rotor. With this apparatus the amplification of various types of amplifier was measured at frequencies between 500 c/s and 3000 c/s and it was shown that the gain of the RCC and choke-coupled amplifier was almost constant over this frequency band, but the gain of a transformer could vary widely at the various frequencies.

**Power Valves**

At this time it was common practice in multi-valve receivers to change the valves around to find the combination which gave the loudest, or the most pleasing, sound. This was rarely the same combination, for a powerful signal often overloaded the last valve of the receiver.

"Which is the best valve?" was always a good question to start an argument but, in general, amateurs preferred the valves which required the least h.t. voltage. Loudspeaker results with only 30 V was a common boast until it was pointed out that there was
little straight portion to the valve characteristic with such a low voltage. It was also being realized that voltage amplification was not so important in the last stage of the receiver, for when the signals were large enough to swing the grid from zero to full current, any further amplification would only overload the valve.

An LS5 valve was often used to operate a large loudspeaker. This valve had originally been designed for the GPO to operate telephone relays and it passed an anode current of 35 mA, but it required an h.t. supply of 300 V and a signal of 20 V at the grid. The valve had an amplification factor ($\mu$) of 5 and an anode a.c. resistance ($r_a$) of 5000 $\Omega$.

Hazeltine had stated that the most important relationship for any valve was the change of anode current which could be obtained for a given signal. Most of the early valves gave a change of only 0.5 mA for each 1 V change at the grid, a ratio called the mutual conductance of the valve. This was shown to be equal to $G_m = \mu/r_a$. An increase in the number of grid wires gave an equal increase of both the $\mu$ and $r_a$ of the valve, and so gave no improvement of the mutual conductance, but two valves in parallel gave twice the change of anode current for the same change at the grid, although the pair also required twice the filament supply.

The advent of the dull-emitter valve had permitted more latitude with filament current and in 1924 the B.T.H. Co. (later Mazda) mounted two sets of electrodes, in parallel, in one bulb to make the B6 valve which was intended for use in the last stage of a receiver. The Marconi-Osram Co. achieved the same result in the DE5 valve by doubling the length of the filament; this was made in the form of an inverted V. The filament required 0.23 A at 5 V, but it gave an emission of 26 mA with only 150 V h.t.

At the Radio Show in 1924 the BBC demonstrated a receiver with RCC stages and a DE5 valve in the last stage. The tone from this receiver was so much better than those normally heard that it caused considerable comment. Many listeners went home to make similar receivers. So successful was this valve that
there was a demand for a similar valve for the RC stage, and the DE5B valve was produced for which \( \mu \) was 20 and \( r_a \) was 26 000 \( \Omega \) \( (G_m = 0.77 \text{ mA/V}) \). This also was an instant success with the quality enthusiasts and the two valves formed the basis of many RCC and choke capacity-coupled amplifiers for the next few years.
The Rediscovery of Short Waves

The Third Transatlantic Test

In 1923 home constructors suddenly found themselves bathed in the reflected glory of the small band of transmitting amateurs. The shock came suddenly with the third transatlantic test which was such a success that it changed the whole future of radiocommunication. Actually, few of the constructors had anything to do with the test. Some had joined a local wireless society and some listened to the amateur r/t transmissions on Sunday mornings—if the BBC was not experimenting—but few knew morse, and fewer still listened to the amateurs when the BBC was transmitting. The majority had only made a receiver to listen to the BBC but, having called themselves amateurs to obtain a licence, they could now share the glory of those who set up long-distance records.

The results of the second transatlantic test in December 1921 had not been very encouraging, for while a few American amateurs had been heard in England, freak DX reception had always been known and there were many amateurs of long standing who still argued that signals on 200 m would never get out of the back-yard. Fortunately there were others who had faith in these wavelengths, or were prepared to try anything once, and made determined efforts...
to obtain the best possible results so as to be ready for the next test. During 1922 they tried every known circuit and developed many gadgets and techniques for providing better operation on these wavelengths.

The move down to 200 m for the rest of the amateur radio fraternity had been Hobson's choice. It was not a choice between working on this wavelength or transmitting after broadcasting had finished, for testing continued into the late hours, and there were always new stations starting up. It was simply a matter of using short wavelengths or stopping operation.

On the short wavelengths the amateur apparatus became almost "wire-less". Gone were the multi-layer coils shellacked and baked in the oven, components screwed onto a horizontal ebonite panel, and connections covered with insulating sleeving, carefully dressed parallel to each other, with right-angle bends as they ran half-way around the receiver. Instead, all components were now mounted on a baseboard which had two brackets to support a vertical panel. The panel held only those components which required to be adjusted—the variable condensers and the filament rheostats. All connections were made in bare wire and as directly as possible, for every endeavour was made to reduce stray capacities. Coils had less than ten turns and were wound with thick wire which required no formers—even copper tubing was used for transmitter coils—small components such as resistors and mica capacitors were hung by their wires between larger components.

R.F. amplifiers and swinging-coil reaction had been discarded and the TA-TG, Hartley and Reinartz tuners had been modified to give smoother reaction control. The favourite circuits used some form of throttle control in which the r.f. was by-passed from the reaction circuit by a variable condenser, but, even then, tuning was difficult and long bars were fitted to the knobs to increase their effective diameter.

For the transmitter, the most favoured circuit was the tuned anode/tuned-grid, for the anode circuit could be set to the required
wavelength, the grid circuit merely being adjusted to give the maximum aerial current, or the least anode current; in practice, the grid circuit could often be left untuned. Some amateurs used the Hartley circuit, which needed only one coil, and the tapping was made by moving a clip along the bare wire.

The aerial also changed; no longer were 100 ft four-wire cages to be seen. Instead, a single-wire aerial was used, often with a counterpoise as long as the aerial and hoisted about 6 ft above the ground.

But even after the amateur had rebuilt his apparatus, at some cost in time and money, he still had troubles with broadcasting stations. Programmes transmitted on wavelengths between 300 m and 500 m could be heard on wavelengths between 150 m and 200 m. This jamming was on submultiples of the stations’ wavelength, and by 1923 the harmonics were so troublesome that amateurs were obliged to request the assistance of the Postmaster General to stop them. In fairness it should be said that the BBC’s engineers, many of whom were also amateurs, did their best to suppress the harmonics.

By the winter of 1922 a high proficiency had been obtained in operating on 200 m, and, even before the start of the third transatlantic tests, expectations of success ran high. Many amateurs had reported hearing broadcasts from American stations, especially station WGY, which gave a very good signal in Britain. American amateur stations were also reported during the preliminary tests, held by the ARRL to select the stations which would transmit in the actual test. The Manchester Radio Society reported hearing 23, 22, and 36 stations on three successive nights.

The third test lasted for ten days, and on these nights the BBC closed down early to permit better conditions. In all, 47 British and two Dutch stations logged 2300 separate receptions of American amateur stations. All the stations selected by the ARRL were heard and, in the free-for-all after the official hours, 94 stations were heard out of the 300 transmitting. Most of these were from the
Atlantic coast, but some were from the Pacific coast and three r/t stations were reported. As K. B. Warner, Secretary of the ARRL, wrote: “You fellows have done the thing so conclusively that there will be no thrill in further attempts”.

With this third test it had also been decided to attempt to conquer the Atlantic in both directions. The Europe to America transmissions were to be after the west/east tests. Reluctantly the Post Office allowed a slight increase of power to a number of British amateurs and, at the last minute, both the RSGB and the Manchester Radio Society were given permission to erect a 1 kW transmitter. These two transmitters, 5SW and 5MS respectively, were a joint effort of the members of the two societies, and used apparatus borrowed for the occasion. The members had only three days in which to erect the stations and none of them had any experience of using such power. Indeed, it was eight times the power of the BBC’s relay stations. Both these stations were heard, but no other British, and only one French, amateur station was reported. It later transpired that few American amateurs even bothered to listen for Europe. Having transmitted for the first ten days, they immediately returned to their normal relay work. An operator on board ship, 2200 miles out from London, reported hearing the French station 8AB, and also the British station 2SH Highgate, London.

The French station 8AB belonged to Leon Deloy, of Nice. He started after the war with a receiving station, and installed a transmitter as soon as the French government gave permission. At first he used a receiver valve for the oscillator, with the supplies obtained by transformers from the a.c. mains. Then he increased his power, first by using two valves in parallel and then by increasing the h.t. to 500 V. The valves became red-hot when keying but this was not considered to be serious, and reports were obtained from a distance of 11 km. When four valves were used in parallel, signals were received at 18 km.

Up to this stage the wires had been twisted together, but when
improvements could be made by merely re-twisting the wires, the whole transmitter was overhauled and the connections soldered. As French amateurs were allowed a power of 100 W, two 50 W valves, a transformer for 1500 V, a choke and blocking condenser were purchased and these gave an aerial current of 2.5 A with reports from 300 km away. At this stage the wavelength was lowered to 360 m, to get away from interference from spark stations, and signals were reported at 800 km. Then a 250 W valve was used, under-run at 100 W, and signals were received in Aberdeen, a distance of 1700 miles. The wavelength was then changed again down to 200 m, and it was with this transmitter that Deloy had the honour of being the first European amateur to be heard in the USA.

Commercial Short Waves

The success of the third transatlantic test came as a bombshell to all engineers who had been convinced that the solution to all wireless communication problems lay in bigger and better long-wave stations. The amateurs’ feat could not even be disparaged as a freak result; the numbers of stations received and the ten days of the tests preventing this. Suggestions were made that high-power long wave stations were obsolete. This produced a letter to The Times from Marconi, who, while warmly commending the amateurs, pointed out that the contacts had been made in the winter months and in the early hours of the morning, times when communication had always been easiest. He still maintained that continuous long-distance communication necessitated powers of 350 kW and wavelengths of 10 000 m, and so the high-power station was not likely to be obsolete in the foreseeable future. This letter expressed the opinion of most engineers and, incidentally, prevented a number of wireless companies from going bankrupt.

But despite this soothing of the shareholders, Marconi saw a use for short waves, even if only for a few hours each night. Non-
priority traffic such as press messages could be sent cheaply in this manner. During 1923 many short-wave transmissions were made from Poldhu and signal strengths were measured on board Marconi's yacht Elettra. Good reception was often obtained but there were large variations of the signal strength with the time of the day and the wavelength used. Marconi also realized that on these short wavelengths all fixed stations could use reflectors. In a resumé of his early work to the Royal Society in July 1924, he showed how the use of a sheet of metal had trebled the distance of his first transmissions in England. He had also proposed reflectors in his patent of 1896, but ships had required all-round working, and this had diverted attention to the longer wavelengths.

Many methods of directional transmission had been patented in the early days. Brown in 1899 proposed the use of aerials spaced half a wavelength apart (Fig. 5.1), and this idea was developed in 1902 by Stone, Braun, and Artom, but the distance between the aerials rendered it impractical for long waves. In 1903 Blondel showed that, provided the aerials were fed in the correct phase,
they need not be half a wavelength apart; at a quarter-wavelength the current in one aerial had to be passing through zero when it was at its crest in the other aerial. Bellini had also suggested that twenty Blondel pairs would radiate a beam in one direction, but the suggestion proved premature because such phasing of r.f. currents was not possible at this time.

During the First World War Marconi and Franklin had experimented with spark transmitters with reflectors on wavelengths of 4 to 5 m, but while a range of 20 miles was obtained when the transmitter aerial was 600 ft above the sea, at sea level only a range of 4 miles was obtained. Such transmissions were used in 1921 for
directional transmissions at Inchkeith, Scotland. Two reflectors, made from a number of vertical wires mounted in a semicircle behind the aerial, were mounted back-to-back on a rotating platform fitted with a switch so that a distinct morse signal was transmitted at each half-point of the compass. By picking out the loudest signal and its code letter, a ship at sea could find its direction from the transmitter. A number of these “Radiophares” were used to replace lighthouses.

In 1919 a valve transmitter was used on 15 m, the shortest wavelength at which the valve could be made to oscillate, and radiotelephony was obtained over distances of 70 miles with an input of 200 W. In 1920 tests were also conducted between London and Birmingham using 700 W on a wavelength of 15 m. The transmitter was mounted in a motor-car with a “fishing-rod” aerial. At 100 miles speech was inaudible, but a reflector gave a strong signal equal to the amplification of two valves. No atmospherics or jamming occurred on this wavelength but some interference was noticed when the car engine was running.

In 1921 Marconi tested duplex r/t between Southwold and
Zandvoort (Holland) using a wavelength of 100 m without reflectors, and a similar wavelength was used for his tests from Poldhu to his yacht. With only 1 kW, and a parabolic reflector at Poldhu (Fig. 5.4), signals were received at St Vincent, 2300 miles away, which were good enough for commercial traffic.

**International Amateur Transmissions**

Meanwhile amateurs continued to break records, despite the opposition from Government bodies. To counter opposition in Britain the RSGB formed a transmitter and relay section, under the chairmanship of Captain Ian Fraser (5SU) the blind MP for Hammersmith. The necessity for this action was soon apparent, for just as the world was waking to new record-breaking transmissions by amateurs, the Postmaster General issued new regulations. These not only required amateurs to record all transmissions and prohibited spark transmitters, but also forbade the use of wavelengths below 150 m and any transmission other than to Great Britain.

The regulation about keeping records was almost a joke, for this was already normal practice. Amateurs had to log their transmissions in order to check QSL cards and every experimenter kept a record of his experiments. The prohibition of spark transmitters
was thought to be reasonable for there were few experiments left to be made with spark sets, and it was agreed that amateurs should try out new techniques (in any case it had been demonstrated that spark sets were not as good as valve transmitters). A similar suggestion had been made in America but this had not been enforced because “tubes” had to be obtained from the monopoly corporations and were very expensive.

But the embargo on the use of shorter waves was quite different. This was a severe setback to British progress. Amateurs had proved the utility of the short waves and to refuse them permission to investigate still shorter waves was not only bad policy but the reverse of the British spirit of fair play. In America a more enlightened government had recognized the usefulness of the amateur movement and had granted them the use of 200-150 m, 80-75 m, 43-40 m, 22-20 m, and even 5-4 m.

Finally, his attempt to restrict communication distances showed the Postmaster General to be out of touch with reality. In May 1923 an Australian amateur had logged 22 American stations from a distance of over 10,000 miles, and in September 1923 2CM of Sydney had maintained communication with 4AA of New Zealand, 1500 miles away, with power reduced to 0.25 mA at 15 V—only 0.004 W! In November 1923 Deloy, working on 100 m, had a regular schedule of two-way contacts with Schnell (1MO), the traffic manager of ARRL, and with Reinartz (1XAM).

Partridge (2KF), one of the few British amateurs who had received permission to operate on wavelengths below 150 m, had listened to the 8AB-1MO contacts and had requested Deloy to put him in touch with the American station. In the true amateur spirit, 8AB asked 1MO to call 2KF and contact was made on 8 December 1923 at 5:45 a.m., with, “Good-morning, some more amateur history in the making, this is Warner of QST. What is the name of your station?” Signals were exchanged with 2KF becoming stronger in the US until, as day broke in Britain, the signals reached a climax and then faded slowly until contact
was lost at 8.30 a.m. The final signal from 1MO read "Going now, very QRZ, this is the end of a wonderful night".

At a further contact, arranged for the following night, 2KF received a message: "Hiram Percy Maxim, President of the ARRL to Admiral of the Fleet, Sir H. Jackson, President of the RSGB. ARRL has great pleasure in transmitting to RSGB greetings by direct amateur contact across the Atlantic. Stop. Expect visit you in London February, Hiram Percy Maxim, from 1MO to 2KF." Other (personal) messages were also received from the officials of the ARRL and addressed to Wireless World, Mr Burnham and Senator Marconi.

Within the next few days Hogg (2SH) and Simmonds (20D, see Fig. 5.5) also contacted America and by the end of January 1924 eight British, three French and two Dutch stations had communicated with the USA or Canada.

The last long-distance shock came in October, 1924, when Goyder (2SZ) established communication with Bell (4AA) of Dunedin, New Zealand at 6.15 a.m. On the following day Partridge, Marcuse and Simmonds also made contacts half-way round the earth, thus setting an end to all long distance records.

Fig. 5.5 Station 20D, Gerrards Cross (1925)
These long-distance contacts brought to light a confusion which could arise due to the issue of the same call sign to stations in different countries. This trouble had arisen previously between the US and Canadian amateurs and a modified “de” intermediate sign had been used to show the country calling. But this was not possible with the large number of countries which were now communicating. Deloy suggested that all call signs should be prefixed by a letter denoting the country of the station: if he called a British station he would send G2GB de F8AB. This idea was quickly taken up and the International Bureau at Berne listed prefixes for all countries.

In February 1924 Maxim called a meeting in Paris with the (published) object of arranging tests and wavelengths for international amateur working. This meeting was attended by most of the European amateur movements, Henroty (Belgium), Gorret (France), Marcuse (UK), Salom (Italy), Groot (Luxemburg), Etas (Spain), and Canderay (Switzerland). From the meeting the International Amateur Radio Union was formed which brought together all amateurs in readiness for the International Wireless Conference held in Geneva in 1925.

By the end of 1924 so many stations were working between 100 m and 130 m that jamming on these wavelengths was nearly as bad as that on 200 m and shorter wavelengths were being used by an increasing number of amateurs. To encourage the use of these waves in America, the ARRL arranged a series of tests on 20 m. In these tests no long-distance contacts were made at night, the longest distance being 100 miles, but contacts were made between the Atlantic and Pacific coasts during the daytime! By January 1925 transcontinental contacts were common on both 40 m and 20 m.

In 1925 Schnell, of ARRL, was requested to install and operate amateur short-wave apparatus in the USS Seattle. During a highly successful cruise he proved the usefulness of these wavelengths to the US naval authorities. Among his many contacts was Marcuse (G2MN) on 45 m when both stations were operated in broad
daylight. In April 1925 Simmonds contacted A2CM (Australia) in daylight and Marcuse contacted the Argentine on a wavelength of 15 m.

The American commercial broadcasting organizations also became interested in these wavelengths. Station KDKA started to broadcast its 425 m programme on 100 m and 68 m, and station WGY broadcast its programme on 109 m and 41·88 m. In France, also, the Eiffel Tower broadcast on 115 m, 50 m, and 25 m. The 115 m transmission was reported by British and American amateurs but only a few French amateurs reported the 50 m, and no one reported the 25-m transmissions; this was considered to be due to the small number of people listening on these very short wavelengths.

The possibility of high aerial efficiency caused the W2XAF station to revert to the original (Hertzian) vertical aerial. The aerial and counterpoise wires were erected, in line, between two 60 ft wooden towers. The tuning coil and ammeter were at the centre of the two wires, 30 ft above ground. The transmitter was in a hut at the base of the masts and power was fed to the tuner by a twin wire feeder. The aerial ammeter was read through a telescope. This doublet aerial was shown to resonate at a wavelength of approximately twice its total length, quite independently of its capacity to the ground. The current flowed from one end of the wire to arrive at the other end just in time to start the return journey; so, in the complete cycle, the current travelled twice the length of the wire. This was a great advantage for the frequency remained almost constant even when the aerial swayed in the wind, rendering a master-oscillator circuit almost unnecessary. The radiation efficiency was also very high. In this aerial the current was largest at the centre of the wire and almost zero near the ends, but there was a large voltage difference between the ends and little voltage between points near to the centre. Energy could be fed into the aerial either to increase the current surging past the centre, or to increase the voltage at one of the wire ends.
Beam Wireless

Instead of having a number of aerials aligned in the direction of the transmission (Stone's method), or a parabola of wires behind the vertical aerial, Franklin patented a system of wires erected as two vertical arrays across the direction of the transmission. These wires were supported by a row of T-shaped masts with the cross-arms made half-a-wavelength long. One end of the cross-arms carried the aerial wires and the other end carried vertical reflector wires. All the aerial wires were energized by a special feeder system which ensured that the phase of each current was the same. This aerial system concentrated the energy into a beam, the angle narrowing as the number of aerial and reflector wires were increased. By concentrating the energy into an angle of 30°, twelve times the power was obtained in the required direction. This type of aerial was developed by the Marconi Co. and in 1924, with a power of 28 kW, a beamed transmission on a wavelength of 92 m was heard in Sydney, Australia. Another beamed transmission was heard in Montreal.

So confident was the Marconi Co. in the beam system that when in 1924 the Postmaster General announced a start to the Imperial Wireless Scheme—a number of high-power stations to communicate with the colonies—it suggested that its contracts should be cancelled in favour of one for short-wave directional stations, even offering to accept no payment until the station had proved its efficiency. This offer was promptly accepted by the Postmaster General, who ordered a beam station to communicate with Canada, and capable of being expanded to other countries. This was to be paid for only when it had communicated at 100 five-letter words per minute, exclusive of any repetitions to ensure accuracy, for 18 hours per day throughout the year. Similar stations to transmit to India, South Africa and Australia were required to operate for 12, 11, and 7 hours per day respectively.

At this time continual technical progress, which caused stations
to become obsolete, had put the Marconi Co. into financial difficulties, and the terms of this contract were, perhaps, the greatest gamble ever undertaken in the history of wireless. Communications on short waves were known to be possible only during the hours of darkness, and politicians, and many financiers, considered the terms to be a colossal joke on the autocratic Marconi Co. The company, however, proceeded with complete confidence and the gamble paid off.

A beam transmitting station with a power of 20 kW was erected at Bodmin, Cornwall, with a similar beam aerial for the receiving station at Bridgwater, Somerset. These were originally designed for a wavelength of 100 m, but unexpected difficulties caused the wavelength to be changed to 26·57 m. During the official tests, speeds of 225 words per minute were demonstrated, and simultaneous two-way communication at an average speed of 150 word/min was carried out for 13 hours per day; the total
traffic was well over 100 word per/min throughout the 24 hours. The Montreal station was opened in October 1926. A similar station, with a transmitter at Grimsby and receiver at Skegness, was opened in July 1927 to transmit to Australia. In September additional transmitters and receivers at these stations operated to South Africa and India, and in October a station at Dorchester began communicating with Brazil and the Argentine and also with America. Each of these stations cost about £50 000, a twentieth of the cost of one of the eight high-power stations originally considered, and each was an immediate success.

**Signal Vagaries**

Long-distance communication and the popularizing of broadcasting had made it necessary to explain some of the peculiarities of wireless signals. Newcomers to wireless had to be assured that no fault had occurred in their receivers. Both the BBC and the receiver manufacturers, as a matter of self-defence, gave explanations of the whistles, jamming and atmospherics which interfered with reception. The whistles had not been difficult to explain, for the novice heard the howl which resulted from turning his own reaction knob too far and could appreciate that similar howls were caused by someone else doing the same thing. The public could also understand jamming from ships' transmitters in coastal districts, or interference from the local station when they listened to a foreign programme, but atmospherics were not so easy. Unnoticed during the winter months when the receiver was new, these noises were often thought to be due to a fault in the receiver. A small summer thunderstorm helped to explain the correlation of flash and noise in the set.

The weakening of signals during the summer months was an even greater difficulty for it was very similar to the effects of a run-down h.t. battery, and the public had to be assured that their sets were not wearing out. Analogies with the change of signal
strength between day and night helped, but when the real cause of these changes was not properly known the analogies were not always helpful.

In the UK, research into the propagation of signals had been undertaken by the Radio Research Board. This Board had been set up in 1920 to interchange information between, and prevent duplication of work by, the various Government departments. Inter-Service rivalry prevented the Board exercising this function. The Board was also supposed to communicate to the public information on Government research, so long as this was not detrimental to the Services. But the Services were always behind the commercial companies both in design and development, so there was little information to pass to the public. It did however publish, belatedly but very thoroughly, reports on the state of the art, and it also conducted researches into fundamental physics and signal propagation.

Atmospherics had been studied from the time of Popoff's original experiments. They were known to be more frequent on the longer wavelengths, and louder when receiving conditions were good. In 1915 Cave used a direction-finder to locate the source of these atmospherics, as an aid to weather forecasting for aircraft. He found so good a correlation between rainstorms and atmospherics that all the d/f stations were asked to plot the directions of atmospherics. Between 1918 and 1920 some 13,000 bearings were taken, most of these coming from the direction of the Alps or the Atlas mountains, and 90 per cent of the bearings were shown to be from points where rain was falling, usually at the advancing edge of a rainbelt.

Eccles showed that, even after a night when they were strong, atmospherics usually vanished just before dawn, though they often returned again after the sun had risen. Stoye (Strasbourg) showed a correlation with the wispy clouds before a barometric depression, when the vapour pressure was high. Atmospherics were least troublesome during periods of high pressure and low
temperature which gave rise to a dry fog. Watson-Watt suggested that the conditions which formed cumulus clouds, the rise of moist air through an unstable atmosphere, caused atmospherics as the charges of these clouds were being equalized.

Watson-Watt also used a cathode-ray tube to take a large number of pictures of these atmospherics, half of which were shown to be non-oscillatory, like signals from a plain-aerial spark-set, and those which did oscillate to be of a longer wavelength than any used for radio transmission. Highly selective filters could not suppress such atmospherics, but merely tended to oscillate at their own tuned frequency under the shock of the incoming atmospherics.

There was also another form of interference often mistaken for atmospherics, particularly in towns. This was shown by Marchant to be due to the common use of electrical devices. A click each time an electric light was switched on or off could be heard a number of houses away. Anyone living near to an electric tram route heard bangs when the points were operated. The tramcar itself could be heard as crackling in the loudspeaker, when the car was both coming and going, for a distance of some hundreds of yards. Continuous crackling was also heard when any d.c. motor was operating owing to the breaking of the current at the commutator. This type of interference was well known to amateur operators with a machine to provide the h.t. supply. The trouble varied with the length of the connecting leads, but could be reduced to near silence by connecting a condenser of $2\mu F$ across the brushes.

**The Heaviside Layer**

The Radio Research Board realized that some explanation of the amateurs' long-distance transmissions was highly necessary. These transmissions had put the cat among the pigeons for propagation theories. From the time when Hertz denied that electromagnetic radiation could be used for wireless-telegraphy, the leading
scientists had continually had to revise their theories and dogma: the impossible was continually shown to happen. The reason given for Marconi rather than Lodge being the first to transmit across the Atlantic was that Lodge knew that radio signals travelled in straight lines. Marconi, not knowing this, showed that they didn’t. Nevertheless, when the scepticism had passed, there was much heartburning in the universities. Further complications arose when it was shown that transatlantic signals were often 1000 times as strong as the values calculated by the Austen-Cohen formula.

Three theories had been offered. Firstly, the resistance of the earth could cause the waves to bend slightly forward, but this effect over the width of the Atlantic was shown to be negligible. Secondly, the density of the atmosphere, and its dielectric constant, could change with height and act as a lens to cause the signals to bend, but this did not account for the strength of the signals at this distance. Thirdly, the waves could be diffracted in the presence of an opaque body (the Earth), but after fifteen years’ work the mathematicians agreed that this alone could not account for the bending.

In 1902, Heaviside in Great Britain and, quite independently, Kennelly in the USA suggested that the upper layers of the earth’s atmosphere could have a conducting layer which prevented signals being radiated too far upwards and caused them to be confined to the earth’s surface. Such a layer had been suggested earlier as an explanation of the earth’s magnetism, but it had received little attention in the textbooks owing to the very large currents which would have been necessary for the explanation to be true.

In 1913 Eccles revived Heaviside’s suggestion by pointing out that ultra-violet light from the sun could ionize the gases in the upper atmosphere to produce a layer of gas containing free electrons. Also, waves passing through such an ionized layer would have an increased velocity which could cause the signal ray to be bent. The return of the waves was then explained by an analogy with light rays passing from one medium to another (an angle
greater than the critical angle caused reflection). He also suggested
that sunspots, caused when the sun radiates large quantities of
ionized matter into space, could vary the ionization. Sunspots
had been correlated with large changes of the earth's magnetism
and with disturbances on long telegraph lines.

The Kennelly-Heaviside layer also accounted for the day and
night variations of signals. During the daytime the heat from the
sun would cause the air to expand and the ionized layer to ascend,
giving less reflection and weaker signals: at night the layer would
descend again. If the layer rose and fell in patches this would account
for the large variations at sunrise and sunset. Signals could also
travel by two or three paths to the receiver, depending on the point
at which it touched the reflecting layer, and these signals could
assist or oppose each other to produce a variation of the signals. It
also provided a reason for the night-effect in d/f work—a scattering
at the point of reflection could give errors of even 90 deg.

In 1920 the ARRL and the American Bureau of Standards
had tested the fading of signals, and had suggested that it could be
due to the reflected ray opposing the ground ray, but at distances
greater than 200 miles, the ground ray was negligible for most
shortwave transmissions. Reinartz suggested that the layer could
account for the "skip", when signals became inaudible at some
75 miles but were heard again at over 200 miles.

Amateurs naturally preferred the layer theory, especially as
contacts on the 40 m and 20 m bands became more common.
Stations inaudible at 200 miles were strong at 3000 miles distance,
and stations 100 miles away were shown to fade out abruptly at
sunset. This fade-out was shown to be two minutes earlier each
night in December and two minutes later each night in January,
an effect which could only be explained by the layer.

The commercial companies also wished to explain the amateurs’
results for, while freak reception might satisfy the shareholders,
they realized that the layer theory would enable long-distance
short wave stations to be established. The variations of signals on
these short waves made engineering difficult. The 15 m signals from the German (Nauen) station to South America were not very satisfactory, being transmitted without reflectors, but in 1925 Goyder in London was able to maintain contact with an Arctic expedition when all other means failed. Marcuse, similarly, kept touch with an expedition in the wilds of Brazil.

Despite this evidence, proof was needed. In September 1925 Smith-Rose and Barfield tried to use a frame aerial to show that signals could be received coming down from the sky. The experiment failed, because signals were reflected again at the ground and then cancelled the downcoming signals. A month later Appleton and Barnett showed there were signals from the upper atmosphere and these were elliptically polarized in accordance with magneto-ionic theory. Calculations put the ionic density of the layer at over 100,000 free electrons per cm$^3$. But the final proof was obtained with the assistance of the BBC. The 2LO transmitter was operated with a continually varying wavelength, and interference phenomena were obtained at a receiver in Cambridge. Greater signal variations were obtained in a loop aerial than in a vertical one, and from the results it was calculated that the waves were coming downwards at an angle of between 65° and 70°, so that the height of the reflecting layer was some 70 to 80 miles above the surface of the Earth. This proof of the existence of the layer opened up the whole field of short waves and many more commercial stations were built within the next few years.
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Radio has been the great love of Mr. W. M. Dalton's life and he writes its story with so infectious an enthusiasm and so intimate a knowledge that his book makes delightful reading. No radio-man, having once dipped into its pages, will be able to resist the temptation to read on to the end; and if he himself knew the early days of radio and the radio industry, what nostalgia he will feel as Mr. Dalton recalls their mysteries and marvels! If he works in the industry today, what interest he will find in learning why radio developed along some lines rather than others or why ideas once deemed impracticable became best-sellers later! If he is a historian of science and technology, what a wealth of detailed information he will find here!